Supplementary Information for:

Groundwater Methane in Relation to Oil and Gas Development and Shallow Coal Seams in the Denver-Julesburg Basin of Colorado

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S1: Summary of Colorado Oil and Gas Conservation (COGCC) groundwater monitoring regulations

COGCC introduced groundwater monitoring regulations in 2005, with revisions in 2009, 2011, and 2013 (Table S1). From 2011-2013, the Colorado Oil and Gas Association (COGA), an industry organization, adopted voluntary groundwater monitoring guidelines that included data reporting to the COGCC. The introduction of mandatory, state-wide water sampling under COGCC Rules 609 and 318A.e/f in 2013 superseded the voluntary program. Rule 609 requires sampling of up to four water wells within a half-mile (0.8 km) radius of new oil and gas well pads. Rule 318A.e/f applies specifically to the Wattenberg Field and requires sampling of only one water well because of the greater density of existing oil and gas wells in that area. Sampling is required within 12 months prior to and 6, 12, and 60-72 months after drilling of new oil and gas wells. Water quality testing includes physical properties (pH, specific conductance, total dissolved solids), dissolved gases (methane, ethane, propane), alkalinity, major anions (Br^-, Cl^-, Fl^-, SO_4^{2-}, NO_2^-+NO_3^-, PO_4^{3-}), major cations (Ca, Fe, Mg, Mn, K, Na), other elements (Ba, B, Se, Sr), presence of bacteria, total petroleum hydrocarbons (TPH), and BTEX (benzene, toluene, ethylbenzene, xylenes). If free gas or dissolved methane > 1 mg/l is detected, additional analysis of free gas composition and $\delta^{13}C_{C_1}$ and $\delta^{2}H_{C_1}$ is required.

Table S1: Summary of COGCC regulatory and COGA voluntary groundwater quality monitoring in the Denver-Julesburg Basin. The Greater Wattenberg Area (GWA) is defined by the COGCC as Townships 2 South to 7 North and Ranges 61 West to 69 West.

Date	Rule or Program	Description
December 2005	Rule 318A.e [a]	Sampling within GWA for infill wells
April 2009	Rule 305.d [a]	Provides for conditions of approval which can require groundwater sampling
September 2011	Rule 318A.e(4) [a]	Expands groundwater sampling to all of GWA
January 2012	COGA [b]	Voluntary baseline sampling
May 2013	Rule 609 [b]	Sampling near all wells statewide (except GWA)
May 2013	Rule 318A.e/f [a]	Increases sample density in GWA

[a] http://cogcc.state.co.us/documents/reg/Rules/LATEST/300Series.pdf
[b] http://cogcc.state.co.us/documents/reg/Rules/LATEST/600Series.pdf

S2: COGCC groundwater data quality control protocols

S2.1: Water Wells: The COGCC analytical dataset represents a compilation of data collected for different reasons by COGCC staff, data submitted to COGCC from a variety of third parties, including consultants collecting samples on behalf of oil and gas companies, and historical data. The data are provided by the COGCC without any quality control; therefore, we implemented quality control protocols as described below.

S2.2: Water Well Metadata: COGCC location metadata were provided as one or more of the following: county, latitude/longitude coordinates, public land survey system (PLSS) grid locations, elevation, well depth, and Colorado Department of Water Resources (DWR) water well permit numbers. Locations were screened by the following criteria:

1) Location had geochemical data.
2) Location could be cross-referenced to DWR well permit.
3) Reported well location was within 1 km of location on DWR permit.
4) Sample date(s) more recent than well completion date and older than well abandonment date, if applicable.
5) In case of discrepancy between COGCC and DWR reported well depths, the DWR depth was assumed to be correct.

From an initial 1453 water wells, 1062 passed the metadata screening criteria (Table S2). For wells within the Denver Basin aquifer system, which is bounded by the extent of the Laramie-Fox Hills aquifer (Fig. 1), aquifer depths were determined using an online tool provided by DWR (http://cdss.state.co.us/onlineTools/Pages/AquiferDetermination Tools.aspx). Water wells outside the Denver Basin aquifer system were classified as within the Dakota-Cheyenne or High Plains aquifer systems (Fig. 1).

S2.3 Water Well Sample Data: Sample data were provided as sample metadata consisting of sample ID, sample collection date, matrix (i.e., gas or water), and analytical lab (if available) and analytical data consisting of parameter description, result value, units, detection limit and data qualifier. Sample measurement dates were not provided. For locations described above, there were 2,117 unique samples. The reason for the 2-fold higher sample count is that separate samples are taken for different types of analysis and due to follow-up sampling. For all samples, units were normalized and values at or below detection limits were 1) converted to zeros or 2) converted to parameter- and sample-specific detection limits. For results reported with a qualifier of below detection limit, but without the corresponding detection limit value, the maximum parameter-specific detection limit was used. Statistical summaries computed using both methods are reported in Tables S3 and S6. Overall differences between the two methods are negligible. Data screening criteria modified from references (41, 42) were applied to all data and included:

1) Samples with gas or water matrix only
2) Samples with matrix-unit compatibility
3) For duplicate samples, duplicates agreed within 10%
4) Samples with acceptable dates (i.e., 1988 to 2014)

Additional screening criteria for free gas concentration and gas isotope measurements consisted of:

5) Total gas concentrations = 90-110 %
6) O_2:N_2 ratio ≤ atmospheric ratio (0.27)
7) Normal C_{1-6} alkane composition (i.e. $C_1 > C_{2+}$)

8) Gas isotope measurements reported with corresponding gas composition

For dissolved gas concentration measurements:

9) Concentrations in order of $C_1 > C_2 > C_3$

10) O_2 concentration ≤ 4 %

For major ions and other dissolved elements:

11) Sodium (Na) concentration ≥ 0

12) Calcium (Ca), magnesium (Mg), or sulfate (SO_4^{2-}) reported with alkalinity or bicarbonate (HCO_3^-) concentration ≥ 0

13) Mg ≤ Ca

14) pH ≥ 5 and ≤ 10

Unreasonable values due to reporting/transcription errors were eliminated, and the sample data were aggregated by calendar day to facilitate cross-plotting of different parameters. After metadata and analytical QA/QC criteria were applied, the final screened dataset consisted of 1,062 water wells and 1,451 sampling events. Note that not all wells were tested for the same suite of parameters. Therefore, the number of wells with dissolved methane measurements (924) is lower than the total number of wells.

S2.4: Measurement Repeatability

Lack of information about sampling and analytical methods, which are known to affect dissolved methane results (11, 21), is a weakness of public domain databases. However, the presence of 260 water wells in the COGCC database that underwent follow-up sampling over a period of up to 20 years allowed for assessment of measurement repeatability, and therefore data quality, by calculation of pairwise differences in analytical parameters. For example, a water well sampled only twice has only one pairwise difference in any given parameter, but a well sampled three times has three pairwise differences, a well sampled four times has six pairwise differences, and so on. The analysis was conducted separately for samples with microbial and unknown methane (assuming that the unknown methane is also of microbial origin), and for samples of thermogenic or mixed source methane, based on $\delta^{13}C_{C1}$ and $C_1/(C_2+C_3)$ criteria described in the main text. Variability in pairwise differences for microbial/unknown samples was assumed to reflect natural hydrological variability combined with sampling and analytical artifacts. Variability in pairwise differences for thermogenic/mixed samples was assumed to integrate additional effects of wellbore contamination and/or remediation; analysis of these samples was conducted for comparison purposes, but the results were not interpreted as a true reflection of measurement repeatability. For concentration parameters (dissolved methane, free methane, free ethane, free propane and $C_1/(C_2+C_3)$ ratio), pairwise differences are reported as difference of the mean (%). For stable isotopes ($\delta^{13}C_{C1}$, $\delta^{13}C_{C2}$, $\delta^{13}C_{C3}$, $\delta^{2}H_{C1}$), pairwise differences are reported as difference in per mil (‰). Non-detects were excluded from the analysis. Results of this analysis show varying levels of measurement repeatability, depending on parameter (Fig. S2). We assume that these results are indicative of COGCC data quality as a whole.

Table S2: Post-screening counts of COGCC groundwater wells and samples by well type and sample reason. Note that the number of wells by sample reason sums to greater than 1,062 due to repeat sampling.

	N wells	N samples
Water Well Type:		
Domestic	831	1162
Stock	98	122
Irrigation	82	101
Commercial	26	32
Monitoring	12	14
Municipal	9	15
Industrial	3	4
Geothermal	1	1
Total	*1062*	*1451*
Sample Reason:		
Regulatory Pre-drill	208	211
Regulatory Post-drill	20	20
Voluntary Pre-drill	194	198
Voluntary Post-drill	75	76
Complaint/Request	55	75
Unknown	689	871

Table S3: Post-screening statistical summary of COGCC groundwater data. To account for statistical uncertainties introduced by the presence of non-detects, values reported at or below detection limits were 1) converted to zeros and 2) converted to parameter/sample – specific detection limits, as described in section S2.3; where different, statistical results separated by "/". Values below detection limits indicated by "bdl".

Parameter	Units	N Samples	N Non-detects	Detection Limit	Mean	Median	Min.	Max.
Physico-Chemical:								
pH					7.95	7.92	6.54	9.97
Conductivity	umhos/cm	871	0	1 - 10	1309	1090	82	8500
Total Dissolved Solids (TDS)	mg/l	871	0	3 - 20	984	740	42	6300
Total Suspended Solids (TSS)	mg/l	966	47	1 - 1.5	6.3 / 12.9	1.2 / 2.0	bdl	254
Turbidity	mg/l	103	23	0.1 - 1	7.2 / 7.3	2.1	bdl	98.1
Total Alkalinity	mg/l	962	4	0.7 - 20	303	267	bdl	1150
Free Gases:								
Nitrogen N_2	mol %	354	0	0.005 - 0.01	42.75	42.03	1.16	97.16
Oxygen (O_2)	mol %	287	5	0.005 - 0.01	2.53	1.54	bdl	20.71
Carbon Dioxide (CO_2)	mol %	357	2	0.005 - 0.005	0.87	0.23	bdl	77.98
Helium (He)	mol %	179	45	0.001 - 0.01	1.69	0.02	bdl	72.80
Hydrogen (H_2)	mol %	310	292	0.001 - 0.01	bdl / 0.01	bdl / 0.01	bdl	1.00
Methane (C_1)	mol %	360	5	0.0002 - 0.005	50.00	54.48	bdl	89.70
Ethane (C_2)	mol %	360	20	0.0001 - 0.005	1.82	0.06	bdl	16.32
Propane (C_3)	mol %	353	192	0.0001 - 0.005	0.64	bdl / 0.01	bdl	6.43
iso-Butane (iC_4)	mol %	357	248	0.0001 - 0.005	0.10	bdl / 0.01	bdl	0.78
n-Butane (nC_4)	mol %	357	246	0.0001 - 0.005	0.15	bdl / 0.01	bdl	1.85
iso-Pentane (iC_5)	mol %	357	252	0.0001 - 0.005	0.04	bdl / 0.01	bdl	0.38
n-Pentane (nC_5)	mol %	357	260	0.0001 - 0.005	0.03	bdl / 0.01	bdl	0.37
Hexanes (C_6)	mol %	98	52	0.0001 - 0.005	0.04 / 0.09	bdl / 0.01	bdl	0.86
Dissolved Gases:								
Methane (C_1)	mg/l	1162	412	0.00001 - 0.1	3.27 / 3.29	0.01 /0.08	bdl	39
Ethane (C_2)	mg/l	738	545	0.001 - 0.15	0.10 / 0.15	bdl / 0.03	bdl	9.1
Propane (C_3)	mg/l	676	646	0.001 - 0.15	0.04 / 0.12	bdl / 0.07	bdl	5.6
Oxygen (O_2)	mg/l	102	11	N/A	1.67 / 1.87	0.36 / 0.89	bdl	12.6
Stable Isotopes:								
$\delta^{13}C$ of Methane ($\delta^{13}C_{C1}$)	‰	314	0	N/A	-67.4	-71.4	-88.1	-39.6
$\delta^{13}C$ of Ethane ($\delta^{13}C_{C2}$)	‰	95	0	N/A	-38.8	-34.5	-51.8	-26.7
$\delta^{13}C$ of Propane ($\delta^{13}C_{C3}$)	‰	37	0	N/A	-26.4	-26.5	-32.4	-17.6
$\delta^{13}C$ of iso-Butane ($\delta^{13}C_{iC4}$)	‰	4	0	N/A	-30.3	-29.9	-32.7	-28.7
$\delta^{13}C$ of n-Butane ($\delta^{13}C_{nC4}$)	‰	3	0	N/A	-25.8	-26	-26.4	-24.9
$\delta^{13}C$ of Carbon Dioxide ($\delta^{13}C_{CO2}$)	‰	7	0	N/A	-18.8	-17.3	-24.2	-13.6
$\delta^{13}C$ of Dissolved Inorganic Carbon ($\delta^{13}C_{DIC}$)	‰	31	0	N/A	-11.5	-11.9	-17.1	-6.1
$\delta^{18}O$ of Water ($\delta^{18}O_{H2O}$)	‰	21	0	N/A	-13.8	-13.8	-15.6	-11.9
$\delta^{2}H$ of Methane ($\delta^{2}H_{C1}$)	‰	310	0	N/A	-259.7	-264.6	-314.8	-103.3
$\delta^{2}H$ of Water ($\delta^{2}H_{H2O}$)	‰	20	0	N/A	-106.9	-105.8	-119.5	-95.3
Dissolved Ions:								
Bicarbonate (HCO_3^-)	mg/l	906	0	0.1 - 20	294	260	19.3	1150
Carbonate (CO_3^{2-})	mg/l	716	588	0.1 - 20	6.2/ 16.5	bdl / 20.0	bdl	99.4
Bromide (Br^-)	mg/l	696	164	0.05 - 1	0.57 / 0.71	0.38 / 0.48	bdl	7.30
Chloride (Cl^-)	mg/l	945	7	0.01 - 10	73.9 / 74.0	42.9	bdl	1130
Fluoride (F^-)	mg/l	701	34	0.03 - 1	1.17 / 1.21	0.99 / 1.00	bdl	5.30
Nitrate (NO_3^-)	mg/l	327	141	0.01 - 1	4.46 / 4.56	0.21 / 0.50	bdl	47.3
Sulfate (SO_4^{2-})	mg/l	914	119	0.01 - 20	363 / 364	183 / 185	bdl	3820
Phosphate (PO_4^{3-})	mg/l	512	302	0.01 - 0.1	0.07/0.1	bdl / 0.05	bdl	3.60
Calcium (Ca)	mg/l	912	0	0.01 - 1	77.2	40.6	0.6	1000
Sodium (Na)	mg/l	926	0	0.005 - 1	210	169	5.5	1800
Potassium (K)	mg/l	891	40	0.01 - 1	4.88 / 4.93	3.67	bdl	52
Iron (Fe)	mg/l	809	453	0.005 - 0.02	0.69 / 0.74	bdl / 0.10	bdl	160
Manganese (Mn)	mg/l	792	244	0.0001 - 1	0.07 / 0.22	0.01 / 0.03	bdl	3.01
Magnesium (Mg)	mg/l	913	16	0.005 - 1	27.8	11.7	bdl	360
Barium (Ba)	mg/l	667	31	0.001 - 0.1	0.05 / 0.06	0.04	bdl	0.32
Boron (B)	mg/l	469	40	0.01 - 0.1	0.20 / 0.21	0.18	bdl	1.76

Table S4: Counts of water wells exceeding the given methane concentration thresholds. For wells with multiple sampling events, the maximum reported values are shown.

Methane (mg/l)	N water wells	% of water wells measured for methane
Not measured	138	-
Not detected	331	35.8
> 0	593	64.2
> 1	261	28.2
> 10	122	13.2
>28	5	0.5

Table S5: Counts of DJ Basin water wells by methane source, as determined by $\delta^{13}C_{C_1}$ and $C_1/(C_2+C_3)$ compositions.

Methane Source	N water wells
Unknown/Not measured/Not detected	851
Microbial	169
Thermogenic	29
Mixed	13

Table S6: Statistical summary of well depth and dissolved sulfate and methane concentrations by groundwater aquifer. Bootstrapped statistics were calculated from resampling with N = 1000. To account for statistical uncertainties introduced by the presence of non-detects in sulfate and methane data, values reported at or below detection limits were 1) converted to zeros and 2) converted to parameter/sample – specific detection limits, as described in section S2.3. Where different, statistical results separated by "/".

Aquifer	N	Parametric Mean	Parametric Median	St. Err.	Bootstrap Median	Bootstrap Lower 95% Conf. Lim.	Bootstrap Upper 95% Conf. Lim.
Well Depth (m):							
Quaternary alluvium	162	20.4	18.6	0.9	18.8	17.7	19.8
High Plains	83	76.7	76.2	3.7	77.4	64.6	91.4
Dakota-Cheyenne	354	87.9	82.3	3.4	83.0	74.6	91.4
Dawson	43	112.0	120.4	4.0	120.1	115.8	122.2
Denver	68	172.1	180.3	6.4	181.2	170.7	192.0
Arapahoe	63	139.7	121.9	12.2	122.5	120.7	128.0
Laramie-Fox Hills (unconfined)	114	54.2	29.9	4.9	30.7	23.2	46.5
Laramie-Fox Hills (confined)	533	173.9	189.0	3.0	187.0	176.8	198.1
Sulfate (mg/l):							
Quaternary alluvium	118	469	358	33.2 / 33.2	360	329	398 / 400
High Plains	69	33.6 / 33.8	15.0	11.0 / 11.0	14.9 / 15.2	12.0 / 13.0	18.0
Dakota-Cheyenne	265	476	283	33.3	286 / 287	255	334
Dawson	39	21.7	11.6	8.7	11.8 / 11.7	10.7	12.7 / 12.6
Denver	60	75.7 / 77.1	9.5 / 11.5	20.6 / 20.5	10.4 / 13.2	4.7 / 6.7	19.0 / 23.5
Arapahoe	42	475 / 487	200 / 215	116 / 115	194 / 212	88 / 101	276 / 300
Laramie-Fox Hills (unconfined)	65	570	313	95.1	313	284	340 / 335
Laramie-Fox Hills (confined)	254	336 / 337	15.0 / 20.0	35.9	29.5 / 32.8	4.0 / 9.7	110 / 102
Methane (mg/l):							
Quaternary alluvium	134	0.05 / 0.08	0.00	0.03	0.00 / 0.01	0.00	0.00 / 0.01
High Plains	76	0.00 / 0.06	0.00 / 0.10	0.00 / 0.01	0.00 / 0.10	0.00 / 0.10	0.00 / 0.10
Dakota-Cheyenne	282	0.22 / 0.24	0.00 / 0.01	0.11	0.00 / 0.01	0.00 /0.01	0.01 / 0.02
Dawson	16	0.17 / 0.18	0.01 / 0.02	0.12	0.02 / 0.03	0.01	0.03 / 0.07
Denver	66	3.60 / 3.61	1.50	0.52	1.83 / 1.77	0.30	3.60 / 3.65
Arapahoe	58	0.82 / 0.82	0.01 / 0.02	0.35	0.01 / 0.02	0.01	0.02 / 0.03
Laramie-Fox Hills (unconfined)	108	0.71 / 0.73	0.00 / 0.01	0.25	0.00 / 0.01	0.00	0.00 / 0.01
Laramie-Fox Hills (confined)	420	8.03 / 8.04	7.60	0.36	7.57	6.75 / 6.70	8.50 / 8.49

Table S7: U.S. Geological Survey (USGS) desorption gas analysis of sidewall cores drilled into the Laramie formation coal from the Huron H Unit #1 well (API # 05-001-08984; Fig. 1). Ethane and higher alkanes were not quantitatively measured (Augusta Warden, U.S.G.S., pers. comm. Sept 2015). Measurements performed in 1991. Available at: (http://cogcc.state.co.us/COGIS/ComplaintReport.asp?doc_num=200009988).

USGS Sample ID	Depth (m)	Air (%)	CH_4 (%)	CO_2 (%)	$\delta^{13}C_{C1}$ (‰)
91034001	185	86.28	13.53	0.2	-69.50
91034002	196	92.78	7.02	0.2	-69.35
91034003	198	83.32	16.45	0.24	-69.74
91034004	211	89.02	10.64	0.33	-69.29
91034005	234	79.64	20.02	0.34	-69.58

Table S8: U.S. Geological Survey analysis of gas from artesian water wells in the City of Greeley, drilled to the so-called "1100 foot sandstone" in the 1880s. Measurements performed in 1984. Data reproduced from reference (17).

Artesian Well #	Date Completed	Depth (m)	Air (%)	CH_4 (%)	CO_2 (%)	C_2 (%)	C_3 (%)	$C_1/(C_2+C_2)$	$\delta^{13}C_{C1}$ (‰)
5	June 1886	392	29.1	70.65	0.15	0.10	0	707	-67.09
6	July 1886	365	31.77	67.83	0.18	0.22	0	308	-67.26

Table S9: Summary of all water wells with thermogenic or mixed gas detected during sampling. For wells with repeat sampling events, the maxima in $\delta^{13}C$ values and minima in gas dryness ($C_1/(C_2+C_3)$) values are shown. Aquifer codes: LFC-c, Laramie-Fox Hills (confined); LFC-uc, Laramie-Fox Hills (unconfined); Ar, Arapahoe; DC, Dakota-Cheyenne.

Case #	Facility I.D.	Town-ship	Range	Depth (m)	Aquifer	Max. Dissolved CH_4 (mg/l)	Max. $\delta^{13}C_{C1}$ (‰)	Max. $\delta^{13}C_{C2}$ (‰)	Max. $\delta^{13}C_{C3}$ (‰)	Min. $C_1/(C_2+C_3)$	COGCC Complaint #	Complaint Date	Cause
1	703540	3n	64w	91	LFH-c	n/a	-43.9	n/a	n/a	6.1	200396246	1/1/98	Wellbore failure (suspected)
2	703217/ 703529[a]	1s	68w	306	LFH-c	n/a	-46.7	n/a	n/a	6.5	200009988	2/1/90	Settled with operator
3	703216	3n	66w	131	LFH-c	n/a	-47.1	n/a	n/a	7.7	786548	9/1/97	Unresolved
4	703207	1n	67w	258	LFH-c	n/a	-48.4	n/a	n/a	5.8	200016437	5/3/01	Wellbore failure
5	703278	1n	67w	221	LFH-c	13.0	-56.4	n/a	n/a	8.9	200029460	8/14/02	Wellbore failure
	703279	1n	67w	226	LFH-c	22.0	-51.0	n/a	n/a	5.0			
	704666	1n	67w	183	LFH-c	10.0	-56.3	-33.1	n/a	7.3	200095358	8/28/06	
6	703281	4n	65w	73	LFH-c	7.4	-43.8	-26.7	-17.6	6.7	200026395	5/10/02	Unresolved
7	703282	1n	67w	213	LFH-c	10.0	-56.6	-33.9	n/a	9.8	200030152	9/5/02	Settled with operator
8	703697	1n	66w	226	LFH-c	16.0	-48.4	-33.4	n/a	3.1	200032354	12/9/02	Unresolved
9	703247	2n	66w	201	LFH-c	n/a	-44.7	n/a	n/a	4.4	200022785	12/27/01	Wellbore failure
10	704130	3n	67w	11	LFH-uc	15.0	-47.1	-29.6	-27.1	4.3	200049157	1/28/04	Wellbore failure
11	703884	6n	66w	206	DC	1.3	-39.6	-34.5	n/a	44.6	200051005	3/9/04	Wellbore failure
12	704597	3n	66w	142	LFH-c	22.0	-50.9	-26.8	-23.7	9.2	200080649	11/30/05	Unresolved
	705590	3n	66w	134	LFH-c	14.0	-71.0	-49.3	n/a	16.9			
13	704679	1s	67w	366	LFH-c	12.0	-68.5	n/a	-32.4	79.7	200095126	7/26/06	Unresolved
14	705016/ 753424[a]	3n	66w	98	LFH-c	24.0	-48.4	-27.4	-24.4	9.7	200101991	1/5/07	Unresolved
15	704769	1s	64w	122	Ar	6.5	-49.1	-32.9	-28.4	3.3	200097544	10/5/06	Wellbore failure
16	705037	2s	63w	122	Ar	1.5	-46.2	-30.5	n/a	5.9	n/a	8/7/07[b]	Unresolved
17	705592	2n	65w	209	LFH-c	38.0	-54.9	-33.5	-29.3	6.4	200196553	9/18/08	Settled with operator
18	705573	2n	66w	219	LFH-c	11.0	-69.7	n/a	-28.1	50.6	n/a	11/10/08[b]	Unresolved
19	752407	3n	66w	91	LFH-c	17.0	-46.1	n/a	-24.0	5.7	200311007	5/25/11	Unresolved
20	705759	3n	66w	112	LFH-c	9.4	-51.6	n/a	-27.3	5.6	200220190	10/16/09	Unresolved
21	705746	4n	65w	37	LFH-c	17.0	-49.1	-28.7	-26.4	5.7	200217527	9/1/09	Wellbore failure
22	703539	4n	65w	162	LFH-c	n/a	-54.3	n/a	n/a	10.3	200271009	9/13/10	Unresolved
23	752670	3n	64w	130	LFH-c	12.9	-51.5	-30.6	-28.4	5.7	200271005	9/13/10	Unresolved
24	750159	3n	66w	122	LFH-c	13.0	-45.5	-28.0	-22.4	14.7	200276485, 200388222	10/11/13	Wellbore failure
	752810	3n	66w	69	LFH-c	6.5	-46.1	-29.2	-25.7	6.5			
25	708101	1n	66w	264	LFH-c	28.0	-50.9	-30.5	-26.2	6.0	200315938	7/13/11	Unresolved
26	750049	2n	66w	177	LFH-c	24.6	-49.9	-29.4	-25.4	6.8	200371511, 200371513	4/10/12	Wellbore failure
	750060	2n	66w	201	LFH-c	24.7	-56.3	n/a	n/a	9.3			

27	752794	1n	67w	244	LFH-c	1.0	-63.1	n/a	n/a	17.7	200402859	4/22/14	Wellbore failure
	752841	1n	67w	251	LFH-c	7.2	-69.3	n/a	n/a	43.3			
	753196	1n	67w	256	LFH-c	18.0	-54.6	-32.1	-27.6	6.4			
	753680	1n	67w	244	LFH-c	16.0	-63.0	-32.2	-27.4	11.2			
28	752520	3n	66w	96	LFH-c	26.0	-48.2	-33.7	-29.2	5.0	200378738	4/23/13	Unresolved
29	752971	1s	68w	253	LFH-c	n/a	-61.4	-33.4	-29.8	14.4	200383678	7/15/13	Unresolved
30	700018	3n	66w	110	LFH-c	12.0	-68.9	-33.6	n/a	176.8	200409931	8/8/14	Unresolved
	752764	3n	66w	134	LFH-c	4.4	-46.0	-29.5	-23.8	10.4			
	753242	3n	66w	76	LFH-c	20.0	-63.5	-30.0	-26.3	19.8			
31	752922	3n	65w	158	LFH-c	39.0	-54.2	-30.0	-26.5	7.1	200398569	2/10/14	Unresolved
32	753244	3n	66w	101	LFH-c	4.9	-45.9	-29.6	-26.4	5.3	n/a	4/24/14[b]	Unresolved

[a] Duplicate facility I.D.
[b] Minimum sample date.

Table S10. Summary of oil and gas wellbore barrier failures resulting in stray gas migration. All 11 wells are vertical wells with short surface casings set above the base of the deepest local aquifer.

Case #[a]	Well API #[b]	Completion Date	Target Formation	Hydraul-ically Fractured ?	Surface Casing Depth (m)	TOC (m)[c]	Braden-head Pressure?	MIT Test?[d]	Source of Leak	N water wells impacted	Distance to impacted water well(s) (m)	NOAV[e] #	Resolution[f]
1	05-123-07220[g]	2/19/71	J-Sand	Yes	63	2060	yes	n/a	Short surface casing	1	343	n/a	RPA
4	05-001-06164	6/22/70	J-Sand	No	41	2262	yes	fail	Short surface casing + casing leak	1	485	1084828	RPA
5	05-123-16027	9/21/92	Codell	Yes	232	1222	n/a	fail	Short surface casing + casing leak	3	94, 112, 247	1120372	RPr
9	05-123-08385	8/7/75	J-Sand	Yes	210	1963	yes	n/a	Short surface casing + wellhead seal leak	1	353	1120365	RPr
10	05-123-07854	9/24/74	J-Sand	No	68	2134	yes	pass	Short surface casing	1	22	1175378	RPr
11	05-123-12383	3/21/85	Codell	Yes	92	1859	n/a	fail	Short surface casing + casing leak	1	131	1126713	RPA
15	05-001-07626	6/17/80	J-Sand	No	65	2145	yes	fail	Short surface casing + casing leak	1	103	200100163	RPr
21	05-123-11848	11/21/84	Codell	No	103	1885	yes	fail	Short surface casing + casing leak	1	307	200222149	RPr
24	05-123-08161	12/2/74	J-Sand	Yes	195	2134	yes	fail	Short surface casing + casing leak	2	539, 898	n/a	RPA
26	05-123-08926	10/5/76	Codell	Yes	65	2161	no	pass	Short surface casing	2	313, 519	n/a	RPr
27	05-123-07787[e]	1/20/75	Sussex	Yes	62	1279	no	n/a	Short surface casing	4	58, 58, 167, 362	200425334	RPA

[a] Refers to case # in Table S9.
[b] American Petroleum Institute well identifier.
[c] Top of production casing cement.
[d] Mechanical integrity test.
[e] COGCC Notice of Alleged Violation.
[f] RPr: remediated and returned to production; RPA: remediated, then plugged and abandoned.
[g] Suspected wellbore failure, all other cases of wellbore failure confirmed by COGCC.
[e] Three other nearby oil and gas wells with similar wellbore designs were also implicated: 05-123-09135, 05-123-08850, and 05-123-08471.

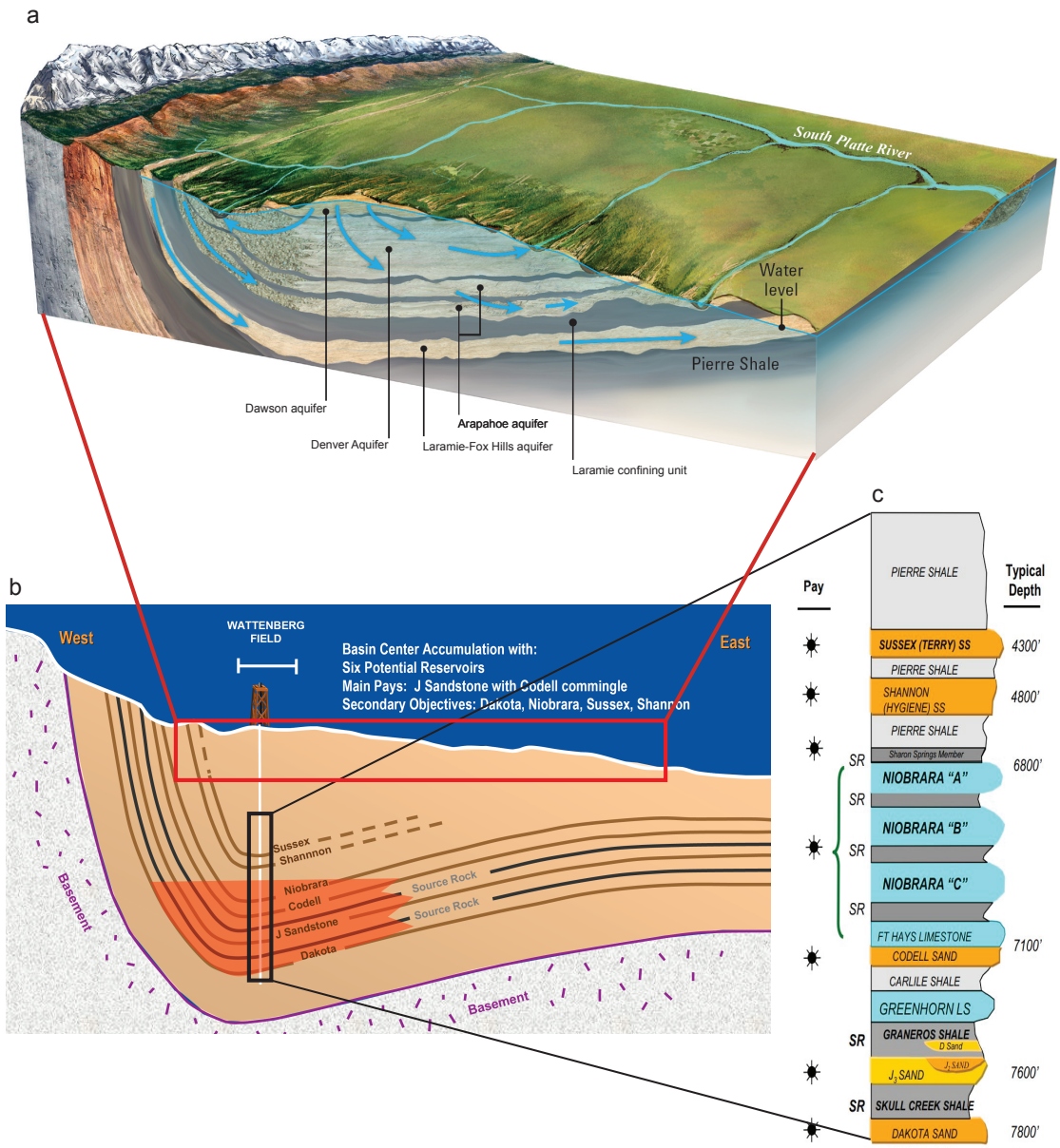

Fig S1: a) Generalized block diagram showing aquifer formations of the Denver Basin aquifer system, reproduced from reference (44). The Denver Basin is a sub-basin within the larger Denver-Julesburg (DJ) Basin. b) Generalized west-east cross section and (c) stratigraphic section of the DJ Basin, reproduced from reference (16), showing oil- and gas-producing formations.

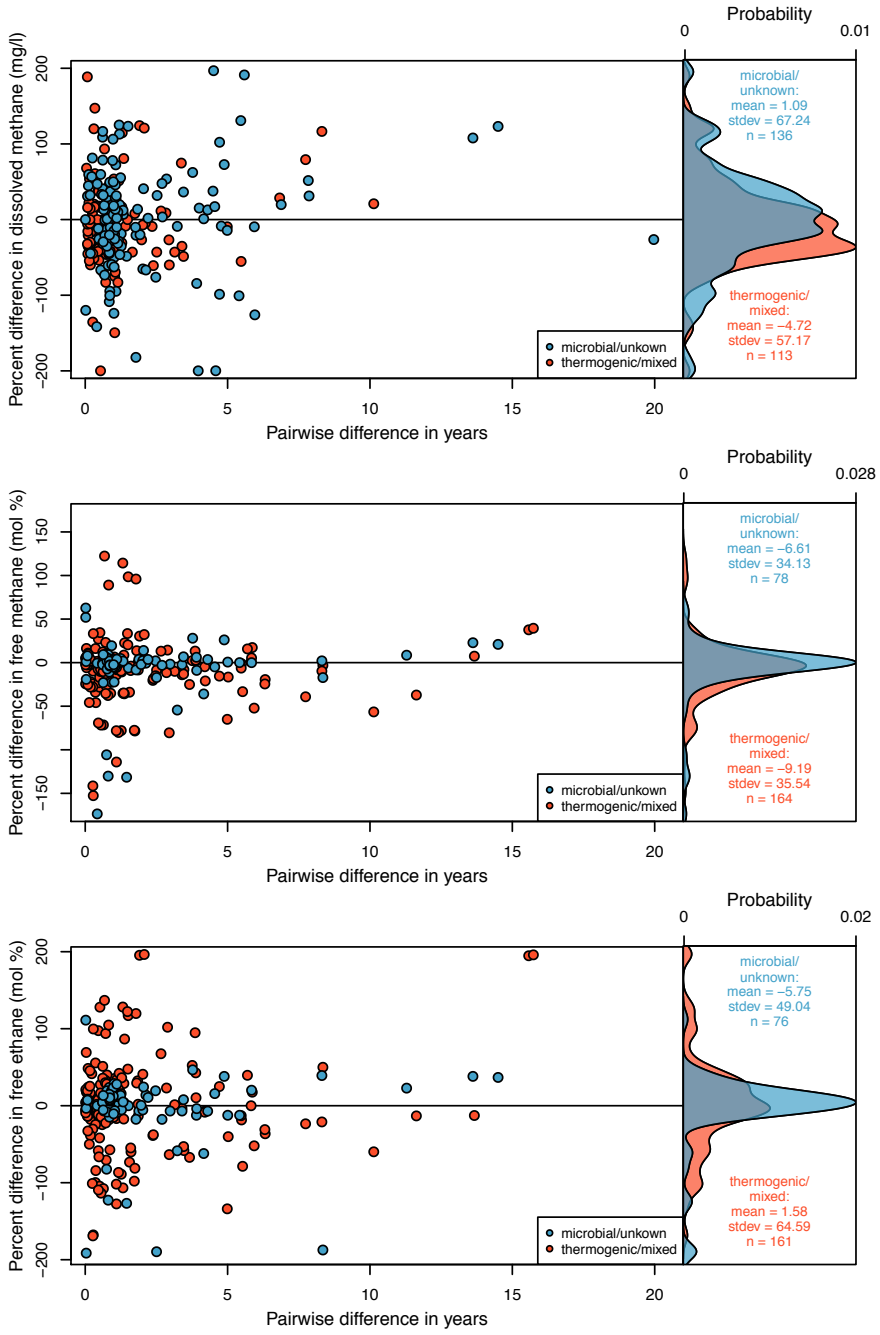

Fig. S2: Measurement repeatability plots showing pairwise differences in analytical parameters vs. time between sampling events, separately for samples with microbial/unknown methane and thermogenic/mixed methane. Non-detects were excluded. Negative values mean that the value at time t_0 was lower than the value at time t_1. Right panels show probability densities and summary statistics.

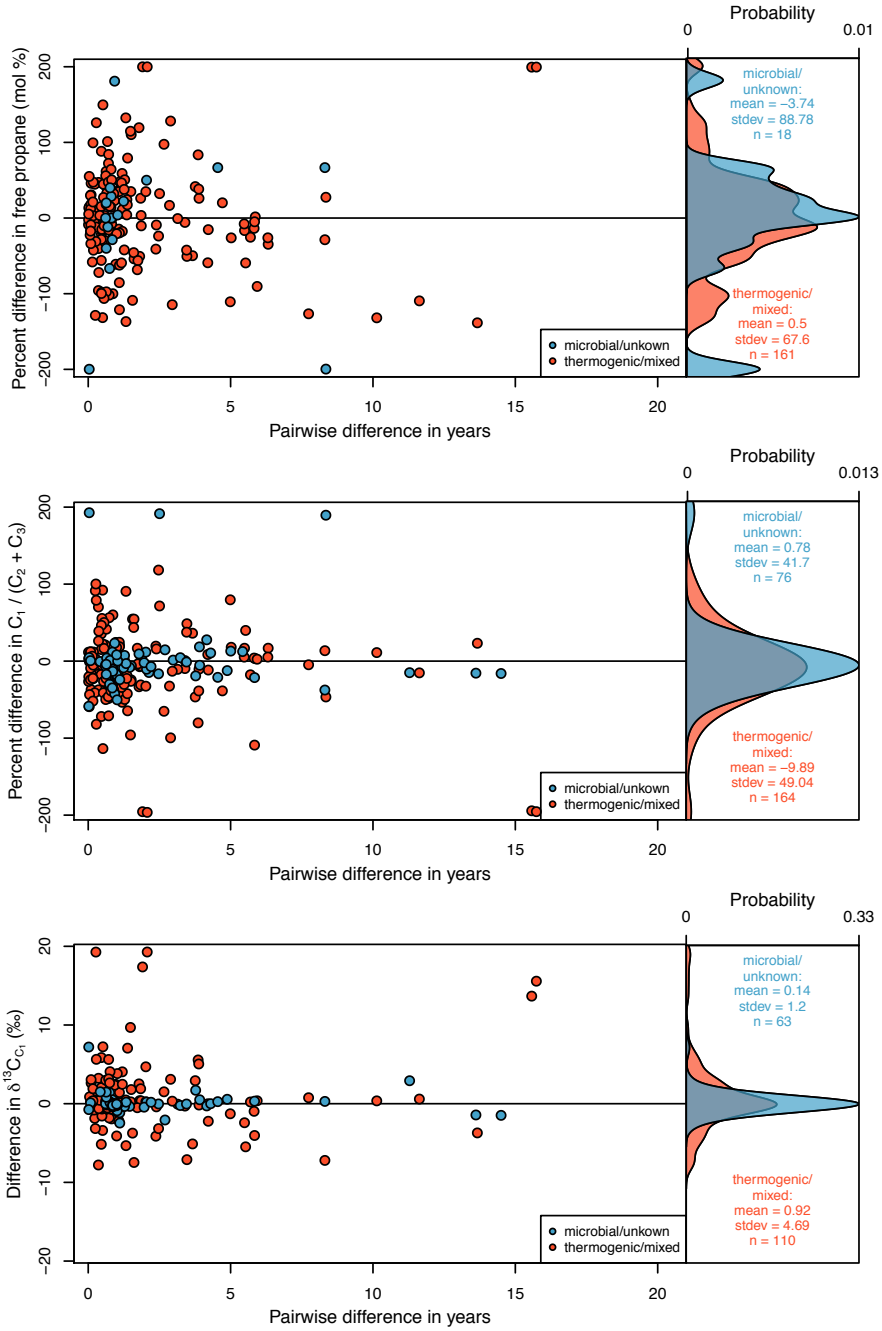

Fig. S2 continued.

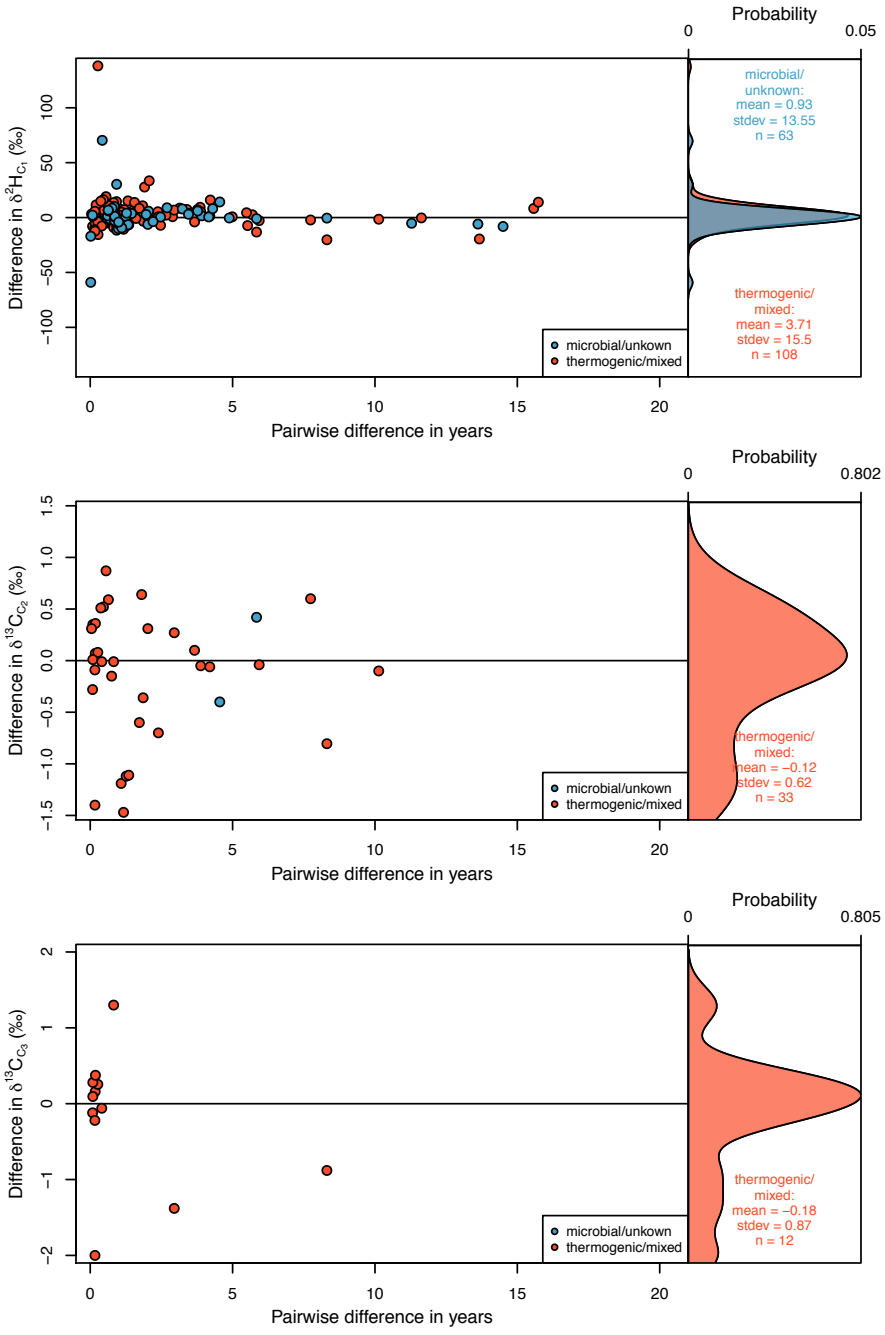

Fig. S2 continued.

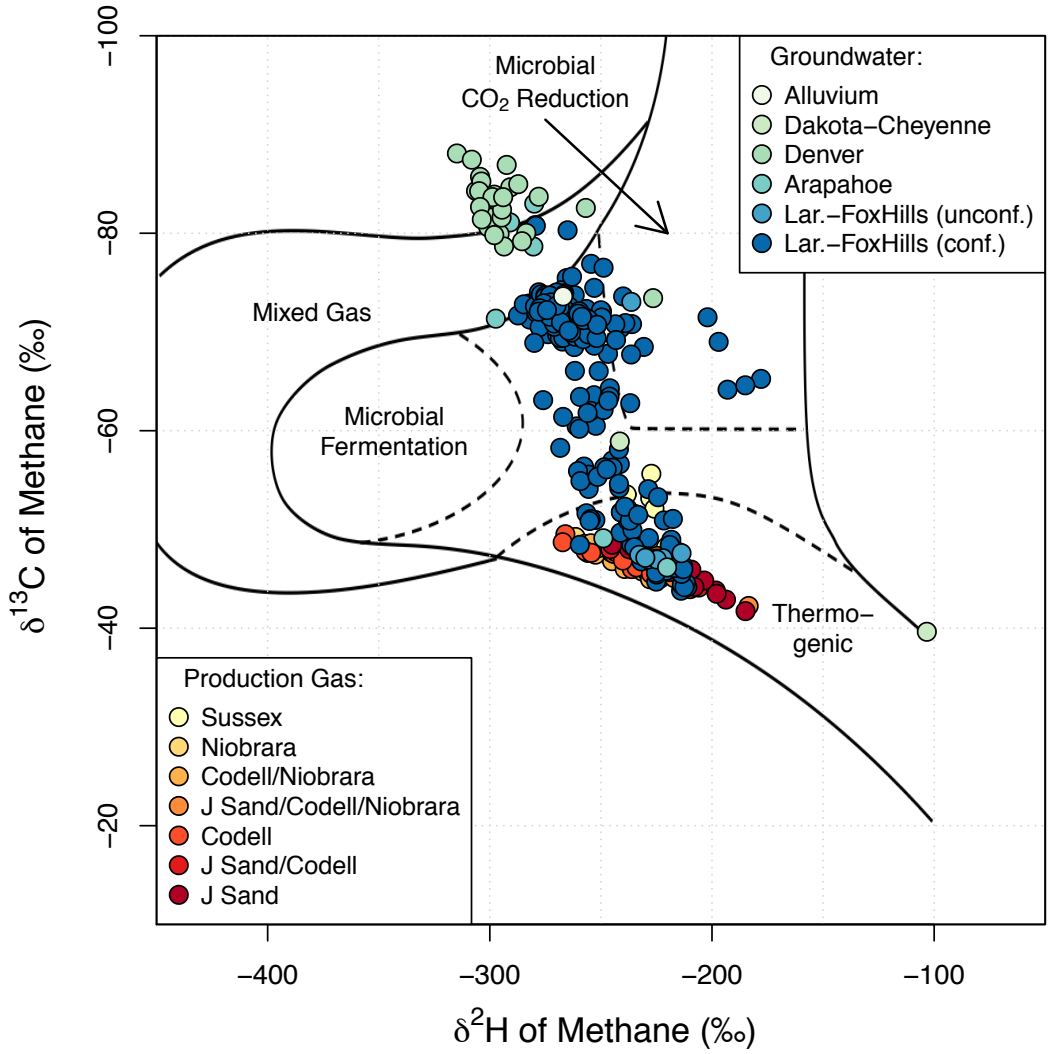

Fig. S3: Genetic characterization plot (22) of $\delta^{13}C_{C1}$ vs. $\delta^{2}H_{C1}$ for DJ Basin groundwaters compared with production gas reservoirs (including co-mingled production). Repeat samples included. Note different isotopic signatures for Denver versus Laramie-Fox Hills groundwaters.

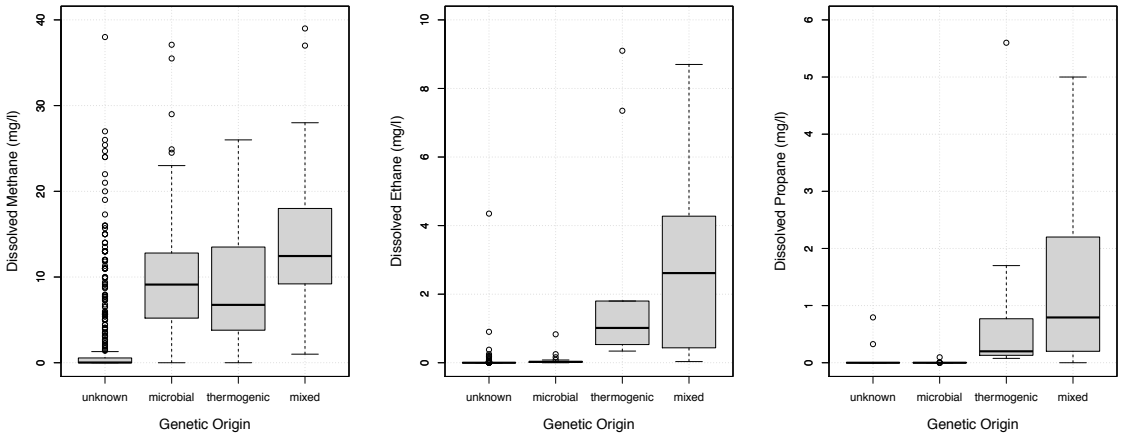

Fig. S4: Box-and-whisker plots of dissolved methane, ethane and propane concentrations versus methane genetic origin, as determined by $\delta^{13}C_{C1}$ and $C_1/(C_2+C_3)$, in DJ Basin groundwaters.

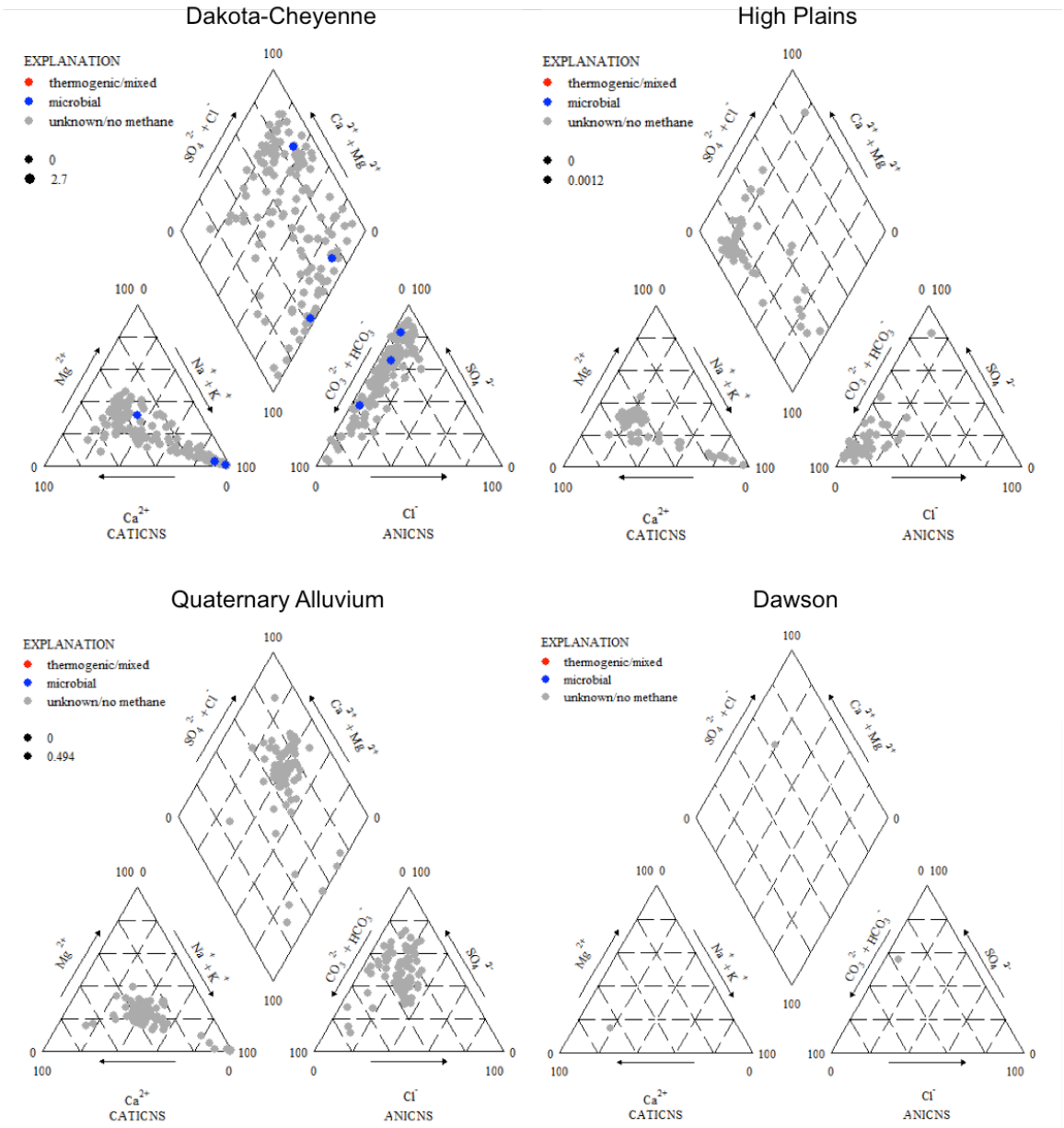

Fig. S5: Piper diagrams for COGCC water samples, by aquifer formation. Points are colored by methane genetic origin, and scaled by dissolved methane concentration.

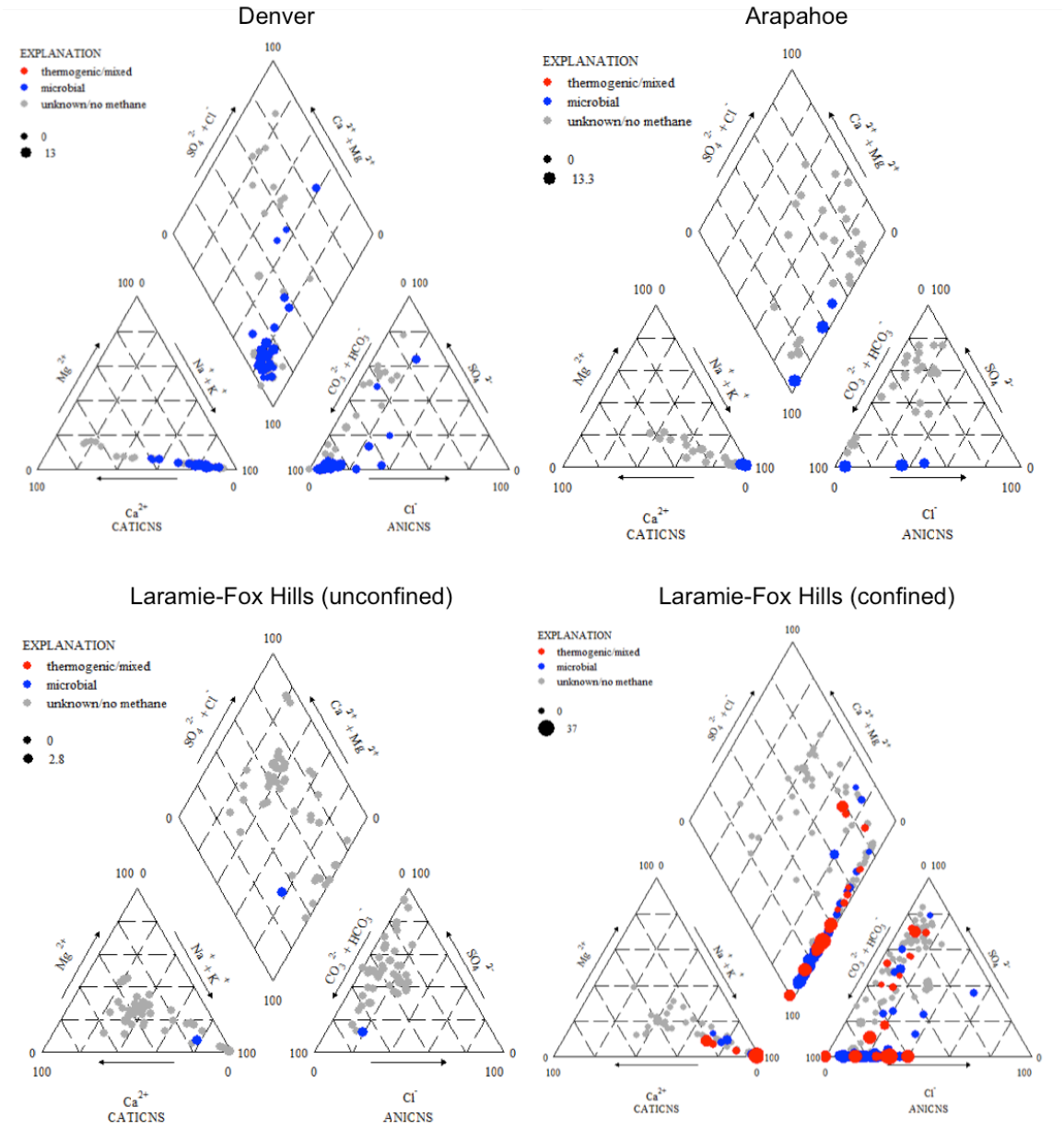

Fig. S5 continued.

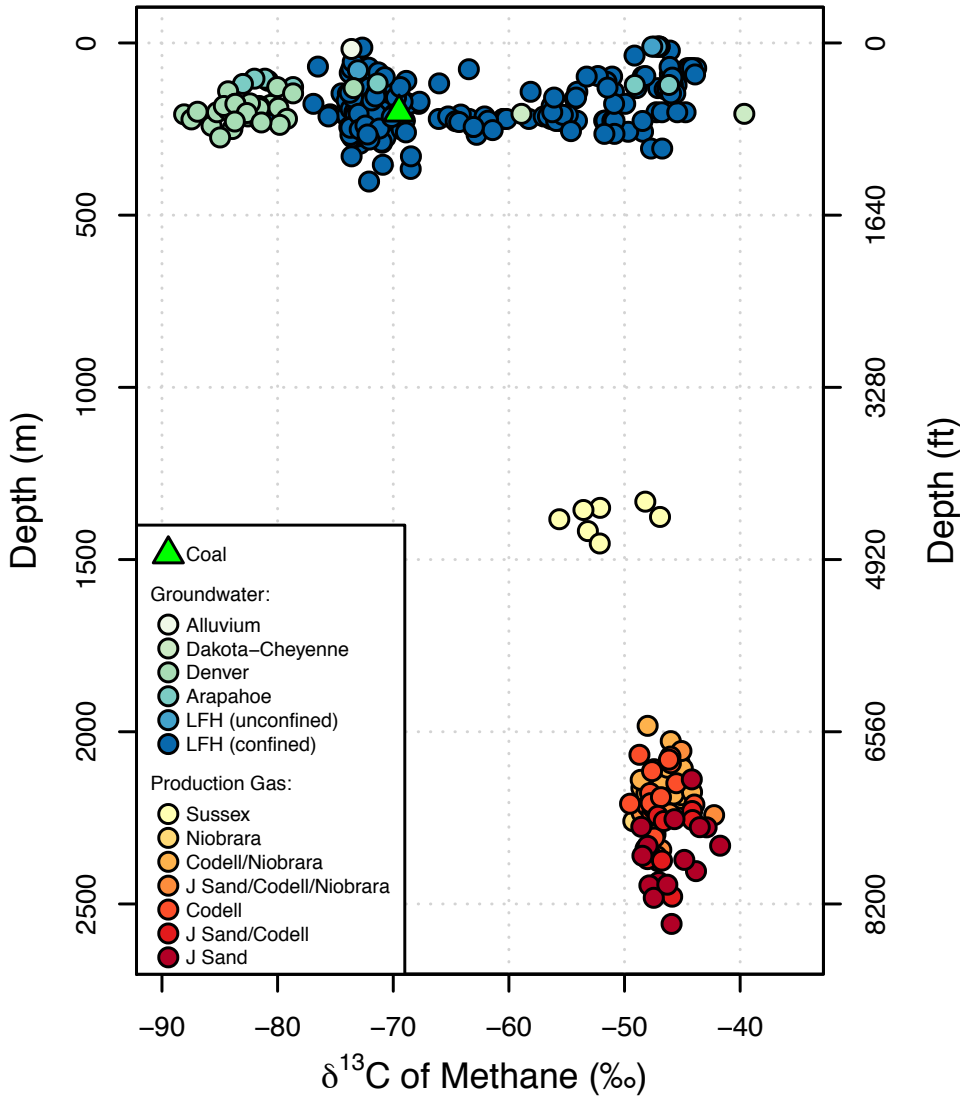

Fig. S6: Depth plot of $\delta^{13}C_{C_1}$ for coal, groundwaters and production gases.

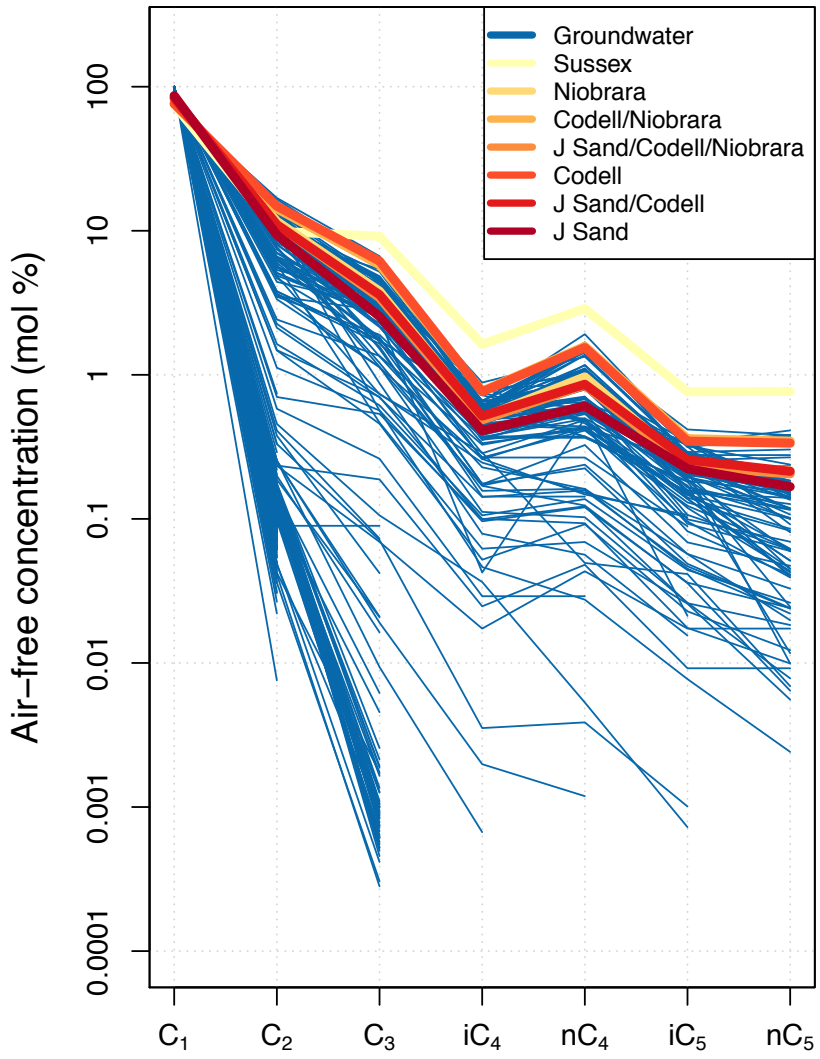

Fig. S7: Gas molecular composition plot for groundwaters (individual samples) and production gases (formation-specific averages).

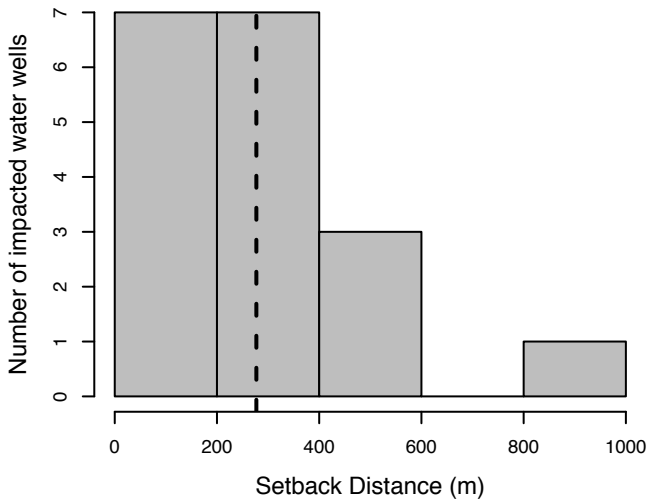

Fig. S8. Offset distance between oil and gas wells with confirmed (*n* = 10) or suspected (*n* = 1) wellbore barrier failures and water wells that were impacted by resulting thermogenic stray gas migration (*n* = 18). Difference in numbers is due to cluster impacts (Table S10). Dashed line shows median distance of 277 m.

S3: Thermogenic stray gas case narratives

The following provides case narratives for 32 separate cases in which a water well or cluster of water wells were impacted with thermogenic stray gas. Case numbers correspond to information in Tables S9 and S10. Narratives are based on information contained in Colorado Oil and Gas Conservation Commission (COGCC) complaint reports, Notices of Alleged Violations (NOAV), remediation reports and oil and gas wellbore construction records (Methods). Maps accompanying each case show the locations of impacted water wells and surrounding oil and gas wells during the year of the incident. Underlying satellite imagery is current and therefore may show additional infrastructure that did not exist at the time of the incident. Tables accompanying each case show relevant water well sample data from initial and selected follow-up sampling events, and surrounding oil and gas wells sampled during complaint investigations. Because it is not possible to show data for all sampling events, data in the accompanying tables may not appear to agree with summary data in Table S9. Note that where more than one lab is indicated per sample date, the first lab corresponds to dissolved methane concentrations and the second lab corresponds to free gas concentrations and stable isotopes.

Case #1 (Suspected wellbore failure: Short surface casing, 1 water well impacted):

Complaint #200396246 was reported in 1988 by a landowner experiencing gas in their domestic water well (FacID # 703540). The water well was completed in the confined Laramie-Fox Hills aquifer at a depth of 91 m. Initial analysis of the water well by the Weld County Department of Health showed high concentrations of C_2+ alkanes, characteristic of thermogenic gas. Additional analysis and interpretation of gas composition in the water well and in three surrounding oil&gas wells was referred to the U.S. Geological Survey (USGS). Analysis of $\delta^{13}C_{C2-C3}$ and $\delta^{2}H_{C1}$ was not performed. Based on compositional and $\delta^{13}C_{C1}$ results, the gas in water well was found to be similar to that of the Amoco UPRR 39 Pan Am A #01 well (API #05-123-07220), located southwest (downdip for the Laramie-Fox Hills formation), of the water well at an offset distance of 343 m. This well was completed on 2/19/1971 in the J-Sand formation at a depth of 2246-2253 m. Surface casing was set to 63 m, which is shallower than the top of the Fox Hills formation at that location (82 m). In addition, the top of production casing cement (2060 m) did not cover the top of the Niobrara formation (2024 m). On 3/19/1988, the well underwent remedial cementing from 152 m to surface in order to protect the Laramie-Fox Hills aquifer. However, the job proved unsuccessful as the oil and gas well continued to register a bradenhead pressure of 552 kPag (80 psig) and the water well continued to produce gas. Amoco Production Co. arranged to deepen and install a gas separator on the landowner's water well "as a good neighbor gesture, and without admitting any liability for the conditions of the water well". On 2/19/1990, the UPRR 30 Pan Am A #01 well was plugged and abandoned. While the Colorado Oil and Gas Conservation Commission (COGCC) did not issue a Notice of Alleged Violation (NOAV) to the operators of this well, gas geochemistry results, problems with the initial well construction and failure to mitigate bradenhead pressure after remedial cementing suggest that the UPRR 39 Pan Am A #01 was the probable source of the gas in water well. Production gases from two other nearby oil&gas wells sampled by USGS (API #05-123-13182 and #05-123-13164) were compositionally wetter and isotopically lighter than the gas in the water well. Both these wells were completed in the Codell/Niobrara formation and surface casings were set below the depth of the Laramie Fox Hills, and thus were not implicated as potential sources of stray gas. An overview of the complaint investigation is shown in Figure 1.

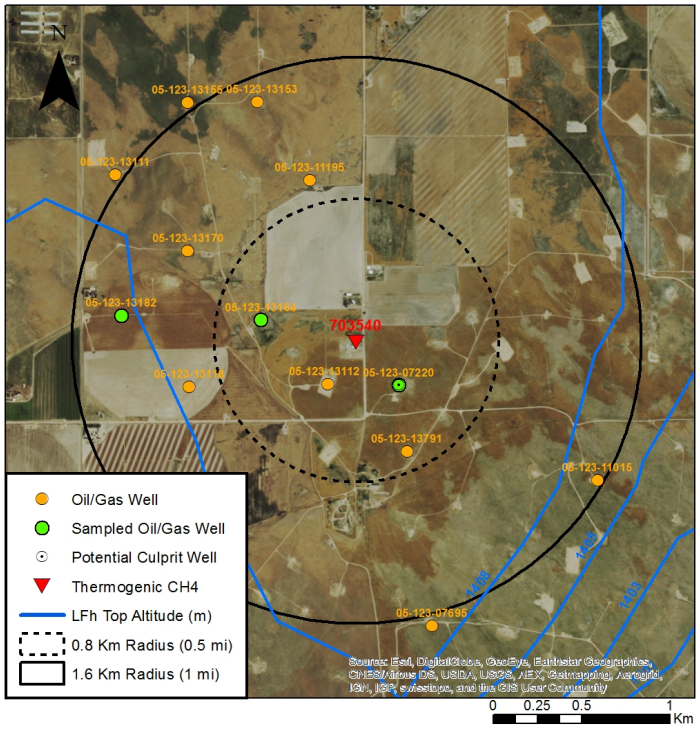

Figure S3.1 - Map view of case #1. All of the completed oil&gas wells and environmental samples collected by the COGCC are shown from the time of the incident. The altitude contour lines of the Laramie-Fox Hills aquifer demonstrate the dip of the formation.

Table S3.1 – Summary of samples collected for gas and isotope analyses in Case #1.

Facility I.D. or Well API Number	Completion Formation	Sample Date	Lab	CH_4 (mg/l)	C_1 (%)	C_2 (%)	C_3 (%)	iC_4 (%)	nC_4 (%)	$C_1/(C_2+C_3)$	$\delta^{13}C_{C1}$ (‰)	$\delta^{13}C_{C2}$ (‰)	$\delta^{13}C_{C3}$ (‰)	$\delta^{2}H_{C1}$ (‰)
Water Well														
703540	LFh	1/27/88	WeldCount	n/a	84.6	10.7	3.1	0.5	0.7	6.10	n/a	n/a	n/a	n/a
		6/7/88	USGS	n/a	83.25	8.37	2.06	0.27	0.46	8.00	-43.9	n/a	n/a	n/a
Oil&Gas Well														
05-123-07220 (prod)	J-Sand	1998	USGS	n/a	85.00	7.10	1.58	0.35	0.37	9.79	-42.9	n/a	n/a	n/a
05-123-07220 (annulus)	J-Sand	1998	USGS	n/a	88.37	7.40	1.75	0.37	0.41	9.66	-43.0	n/a	n/a	n/a
05-123-13182 (prod)	Cod/Nio	1998	USGS	n/a	73.46	14.14	5.79	0.85	1.6	3.69	-45.6	n/a	n/a	n/a
05-123-13164 (prod)	Cod/Nio	1998	USGS	n/a	66.97	12.63	11.97	1.48	2.93	2.72	-45.3	n/a	n/a	n/a

Case #2 (Settled, 1 water well impacted):

Complaint #200009988 was opened with the COGCC in February of 1990 when the pump house of the North Washington Water User's Association (NWWUA) south water well (FacID# 703217) was destroyed by an explosion. The NWWUA provided water for a community of approximately 50 homes. The NWWUA south well was drilled in 1958 and completed in the confined Laramie-Fox Hills aquifer at a depth of 306 m. The three closest oil&gas wells to the NWWUA south well producing from the J-Sand were the Sharpe #1-10 (API #05-001-08512), Bydalak #1-11 (API #05-001-08881), and Shannon #14-5 (API #05-001-08842). These wells were originally drilled by Martin Exploration & Management Company (Martin) and acquired by Patina Oil & Gas Corporation (Patina) during the investigation of this complaint on 12/31/1992. In response to the complaint, the COGCC took samples from the water well on 2/21/1990, 3/6/1990 and 1/3/1996. Dissolved methane concentrations were not measured in the samples nor were $\delta^{13}C_{C2-C3}$ determined. However, the compositional and $\delta^{13}C_{C1}$ results indicated that gas was of thermogenic origin (Table S3.2) and characteristic of the J-Sand. Gas samples from the Shannon #14-5 and the Sharpe #1-10 were collected on 3/16/1990 and analyzed for composition and isotopic signature. The USGS noted the similarities between the 3/6/1990 NWWUA water well sample and the 3/16/1990 sample from Shannon #14-5 in their report. Mechanical integrity tests (MITs) were passed by all three nearby wells in April and August of 1990. Mudlogging one mile southeast of the NWWUA water well showed gas in the Pierre B zone (Upper Pierre aquifer) at a depth of 1,030 feet, however, not enough gas was present for isotopic analysis. In September of 1990, the COGCC reviewed all nearby oil&gas wells within 2 miles of the NWWUA well for compliance and found that no wells exhibited significant bradenhead pressure. It was noted that the effectiveness of this test was severely limited because many of the investigated wells had additional cement added to the bradenhead to provide coverage for the Laramie-Fox Hills aquifer. Gas composition and $\delta^{13}C_{C1}$ confirmed that the gas from coals in the Laramie-Fox Hills aquifer have a microbial signature distinct from the thermogenic signature of the gas found in the NWWUA south well. The COGCC never identified a "culprit" well because none of the nearby oil&gas wells ever failed a MIT or exhibited bradenhead pressure. Martin and Patina collectively paid reparations to the NWWUA and the complaint was never closed. An overview of the complaint investigation is shown in Figure S3.2.

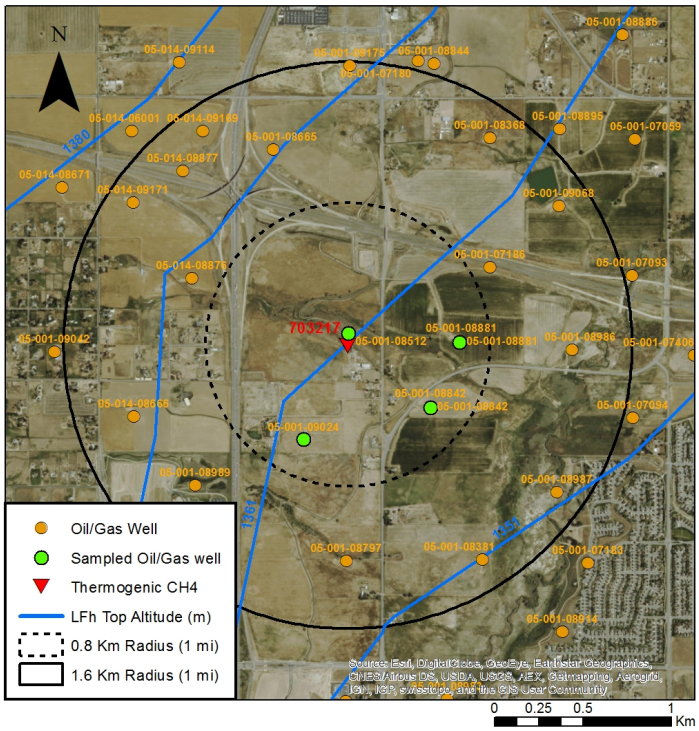

Figure S3.2 - Map view of case #2. All of the completed oil and gas wells and environmental samples collected by the COGCC are shown from the time of the incident. The altitude contour lines of the Laramie-Fox Hills aquifer demonstrate the dip of the formation.

Table S3.2 – Summary of samples collected for gas and isotope analyses in Case #2.

Facility I.D. or Well API Number	Completion Formation	Sample Date	Lab	CH_4 (mg/l)	C_1 (%)	C_2 (%)	C_3 (%)	iC_4 (%)	nC_4 (%)	$C_1/(C_2+C_3)$	$\delta^{13}C_{C1}$ (‰)	$\delta^{13}C_{C2}$ (‰)	$\delta^{13}C_{C3}$ (‰)	$\delta^{2}H_{C1}$ (‰)
Water Well														
703217	LFh	2/21/90	USGS	n/a	72.36	8.55	2.56	0.5	0.55	6.51	n/a	n/a	n/a	n/a
		3/6/90	USGS	n/a	85.2	10.2	2.98	0.57	0.56	6.46	-46.74	n/a	n/a	n/a
Oil&Gas Well														
05-001-08842 (prod)	J-Sand	3/16/90	USGS	n/a	81.35	11.5	3.2	0.51	0.58	5.53	-46.44	n/a	n/a	n/a
05-001-08512 (prod)	J-Sand	3/16/90	USGS	n/a	77.06	13.1	4.63	0.89	1.01	4.34	-46.40	n/a	n/a	n/a
05-001-08881 (prod)	J-Sand	1/12/96	GCC	n/a	81.2	10.6	3.1	0.5	0.7	5.92	-47.57	n/a	n/a	-215

Case #3 (Unresolved, 1 water well impacted):

Lesh Drilling Inc. (LDI) encountered large quantities of natural gas while drilling a water well (FacID # 703216) for a landowner on 8/20/1997. Complaint #786548 was opened when LDI requested that the COGCC look into the origin of the gas. The water well was completed in the confined Laramie-Fox Hills aquifer at a depth of 131 m. It was noted that beneath the water well the main sandstone of the Laramie-Fox Hills is 58 m deep. Thus, the impacted water well was actually completed somewhere in the upper Pierre Shale or the transition zone between the Upper Pierre Shale and the Laramie Fox Hills aquifer. Samples from the water well and seven nearby oil&gas wells were collected on 9/24/1997 and analyzed by the USGS. Methane concentrations and $\delta^{13}C_{C2-C3}$ were not determined. Gas composition and $\delta^{13}C_{C1}$ of the samples confirmed that the gas in the impacted water well was thermogenic in origin, however, it did not appear to be a direct match to the gas from the oil&gas wells sampled. Additional samples of the # 703216 water well as well as 22 nearby oil&gas wells were taken on 12/16/1997. Sixteen nearby wells registered bradenhead pressures. Samples were taken from the bradenhead of the 16 wells and analyzed for gas composition and isotopic signature. The COGCC determined that the thermogenic gas in the water well was distinct from all of the production and bradenhead gases analyzed within the vicinity. Throughout the investigation, the COGCC performed bradenhead tests on over 100 nearby oil&gas wells and looked into their construction details. No "culprit" oil&gas wells were identified. As a result, the COGCC did not issue a NOAV to any of the operators in the region. The landowner settled with HS Resources Incorporated on 2/11/1998 when they agreed to pay for the drilling of a new water well. However, HS Resources backed out of this agreement on 2/27/1998 after they were informed by the COGCC that there was no evidence available that suggested the gas in the landowner's water well came from nearby oil&gas operations. Table S3.3 summarizes the isotope and compositional analyses from the water well samples and the three closest oil&gas wells. An overview of the complaint investigation is shown in Figure S3.3.

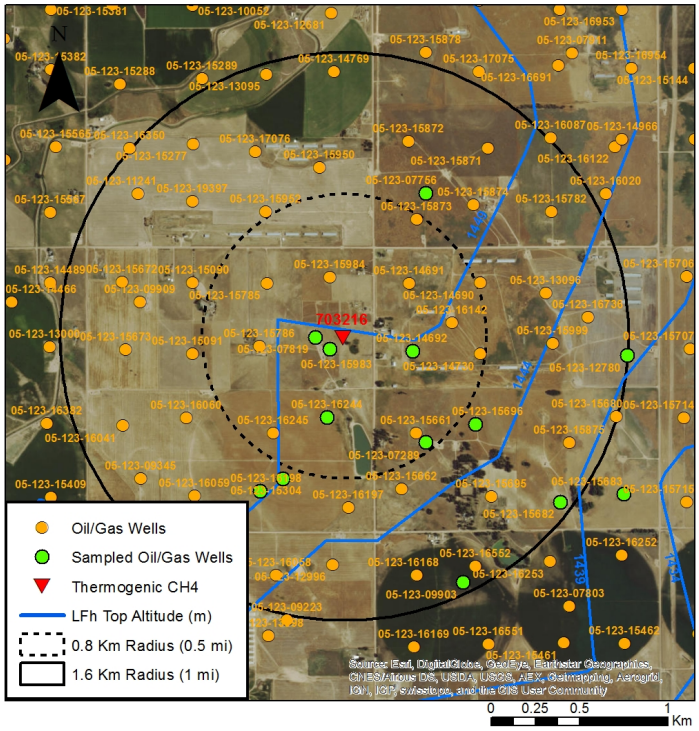

Figure S3.3 - Map view of case #3. All of the completed oil and gas wells and environmental samples collected by the COGCC are shown from the time of the incident. The altitude contour lines of the Laramie-Fox Hills aquifer demonstrate the dip of the formation.

Table S3.3 - Summary of samples collected for gas and isotope analyses in Case #3.

Facility I.D. or Well API Number	Completion Formation	Sample Date	Lab	CH_4 (mg/l)	C_1 (%)	C_2 (%)	C_3 (%)	iC_4 (%)	nC_4 (%)	$C_1/(C_2+C_3)$	$\delta^{13}C_{C1}$ (‰)	$\delta^{13}C_{C2}$ (‰)	$\delta^{13}C_{C3}$ (‰)	$\delta^{2}H_{C1}$ (‰)
Water Well														
703216	LFh	9/24/97	Isotech	n/a	83.87	7.55	2.31	0.04	0.47	8.5	-47.1	n/a	n/a	n/a
		12/16/97	Isotech	n/a	80.6	7.91	2.62	0.43	0.64	7.65	-48.96	n/a	n/a	-218.3
Oil&Gas Well														
05-123-07819 (prod)	J-Sand	12/16/97	Isotech	n/a	83.35	7.97	2.41	0.45	0.67	8.03	-44.68	n/a	n/a	-200.6
05-123-15983 (prod)	J-Sand	9/24/97	USGS	n/a	83.11	10.52	3.15	0.04	0.82	6.07	-43.07	n/a	n/a	n/a
05-123-16244 (prod)	J-Sand	9/24/97	USGS	n/a	81.90	10.07	3.46	0.1	1.02	6.05	-43.49	n/a	n/a	n/a

Case #4 (Wellbore failure: Short surface casing and casing leak, 1 water well impacted):

Mountain View Water Users Association (MVWUA) owned three water wells that supplied 128 homes with water. After the explosion of a pump house, MVWUA reported gas in one of their water wells (FacID # 703207) to the COGCC on 5/3/2001, which opened complaint #200016437. The water well was drilled 258 m deep into the confined Laramie-Fox Hills aquifer. The COGCC sampled the water well on three separate occasions 6/14/2001, 1/18/2002, and 3/19/2004 (Table S3.4). The isotope and gas composition results from the first two sampling events indicated the presence of thermogenic gas characteristic of the J-Sand. Methane concentrations and $\delta^{13}C_{C2-C3}$ were not determined in the water well. After determining that the gas in the MVWUA water well was thermogenic, the COGCC required all nearby oil&gas wells to perform bradenhead pressure tests. The Degenhart #1 (API #05-001-06164), an oil&gas well targeting the J Sand and located 485 m away from the impacted water well, reported a significant bradenhead pressure. Merit Energy Company, the operator of the well, had previously repaired a casing leak in the Degenhart #1 well between the depths of 538 m and 582 m. To investigate the structural integrity of the Degenhart #1 well, the COGCC requested that Merit Energy Company perform a MIT by 8/10/2001. Merit Energy reported a new hole in the casing of the Degenhart #1 well between the depths of 371 m and 380 m. Surface casing in the Degenhart #1 well was set to 41 m, which was shallower than the depth of the impacted water well. The Degenhart #1 well was remediated with a cement squeeze job and passed a follow up MIT on 8/14/2001. Merit Energy was issued a NOAV for the failed MIT. The COGCC installed a gas flowmeter on the MVWUA water well and measured a significant drop in the flow rate of the gas between 8/14/2001 and 12/8/2001. A follow up sample was taken from the well on 3/19/2004 and no methane was found. The complaint investigation was closed by the COGCC on 8/21/2012 when MVWUA agreed that Merit Energy had addressed all of the issues of the complaint. An overview of the complaint investigation is shown in Figure S3.4.

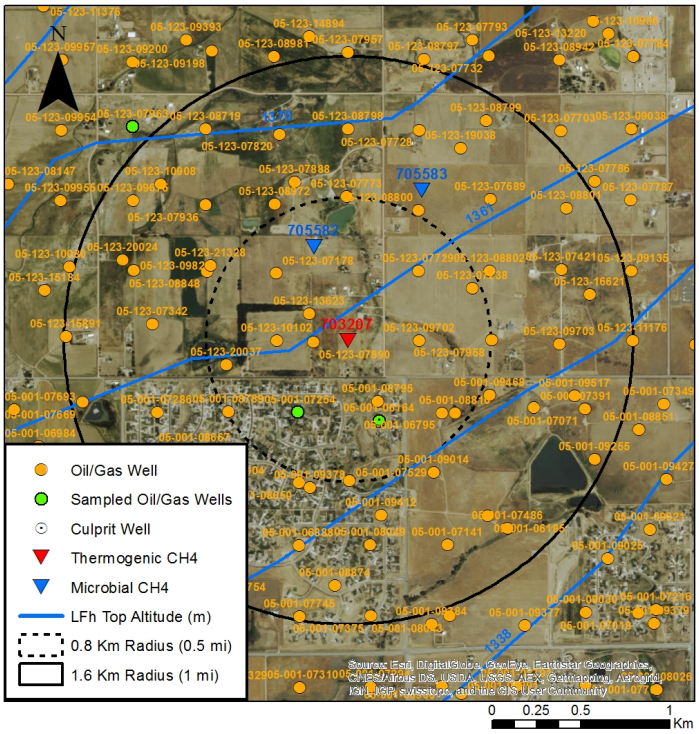

Figure S3.4 - Map view of case #4. All of the completed oil and gas wells and environmental samples collected by the COGCC are shown from the time of the incident. The altitude contour lines of the Laramie-Fox Hills aquifer demonstrate the dip of the formation.

Table S3.4- Summary of samples collected for gas and isotope analyses in Case #4.

Facility I.D. or Well API Number	Completion Formation	Sample Date	Lab	CH_4 (mg/l)	C_1 (%)	C_2 (%)	C_3 (%)	iC_4 (%)	nC_4 (%)	$C_1/(C_2+C_3)$	$\delta^{13}C_{C1}$ (‰)	$\delta^{13}C_{C2}$ (‰)	$\delta^{13}C_{C3}$ (‰)	$\delta^{2}H_{C1}$ (‰)
Water Well														
		6/14/01	Isotech	n/a	80.66	10.68	3.33	0.53	0.79	5.75	-48.4	n/a	n/a	-236.3
703207	LFh	1/18/02	Isotech	n/a	76.82	9.34	2.46	0.37	0.58	6.51	-49.68	n/a	n/a	-241.2
		3/19/04	Isotech	n/a	0.04	0.02	n.d.	n.d.	n.d.	2	n/a	n/a	n/a	n/a
Oil&Gas Well														
05-001-06164 (prod)	J-Sand	5/25/01	Isotech	n/a	78.35	11.7	3.66	0.88	0.54	5.1	-47.76	n/a	n/a	-236.7

Case #5 (Wellbore failure: Short surface casing and casing leak, 3 water wells impacted):

Complaint # 200029460 was reported on 8/14/2002 when landowners complained that water from their domestic water well (FacID #703278) tasted strange, had a sheen to it and left an oil ring in the toilet. The water well was completed in the confined Laramie-Fox Hills aquifer at a depth of 221 m. Gas composition and isotope analyses of a sample taken from the water well on 3/20/2002 indicated the presence of mixed microbial and thermogenic gas (Table S3.5). On 3/27/2002, Patina Oil and Gas Corporation found holes at a depth of 396 m in the production casing of the Scheidt State VV 16-13 well (API # 05-123-16027) located 94 m from the water well. Surface casing in the Scheidt State VV 16-13 well was set to 232 m, a similar depth to the impacted water well (221 m) and above the bottom of the Laramie-Fox Hills formation at that location (247 m). After identifying the holes, Patina remediated the well by filling the bradenhead with cement from 485 m to surface. Bradenhead pressures were not measured prior to the remediation. The Scheidt State VV 16-3 well passed a mechanical integrity test on 4/4/2002. Patina Oil and Gas Corporation was issued a Notice of Alleged Violation (NOAV) on 6/19/2002 for the casing leak. Samples of the production gas from the faulty well were taken on 6/21/2002 for compositional and isotopic analyses (Table S3.5). After complaints from the landowners about the presence of gas in a second water well (FacID #703279), additional samples were taken from both water wells on 7/29/2002. Continued sampling of the impacted water wells took place until 2006. In total, 9 samples were taken from well #703278 and 5 samples were taken from well #703279. All of these samples indicated the presence of mixed microbial and thermogenic gas. Methane concentrations ranged between 8-13 mg/l in well #703278 and 10-22 mg/l in well #703279. Additional sampling in the region of the impacted water wells discovered a third water well (FacID # 704666) with mixed microbial and thermogenic methane at a concentration of 10 mg/l. This resulted in the opening of a second complaint (#200095358) with the COGCC that was filed on 8/28/2006. The COGCC determined that the microbial methane originated in coals embedded in the Laramie-Fox Hills formation and that the thermogenic methane was coming from the Scheidt State VV 16-3 well, which is down dip (relative to the base of the Laramie-Fox Hills formation) from the impacted water wells. The COGCC concluded that the casing leak in the Scheidt State VV 16-13 was responsible for the thermogenic gas and issued Noble Energy Production Inc., the company that bought the well from Patina Oil and Gas Corporation, a NOAV on 10/5/2006. No BTEX compounds were ever detected in any of the impacted water wells and the operator negotiated a settlement with the landowners on 8/10/2006. The complaint investigation was closed on 6/13/2015. An overview of the complaint investigation is shown in Figure S3.5.

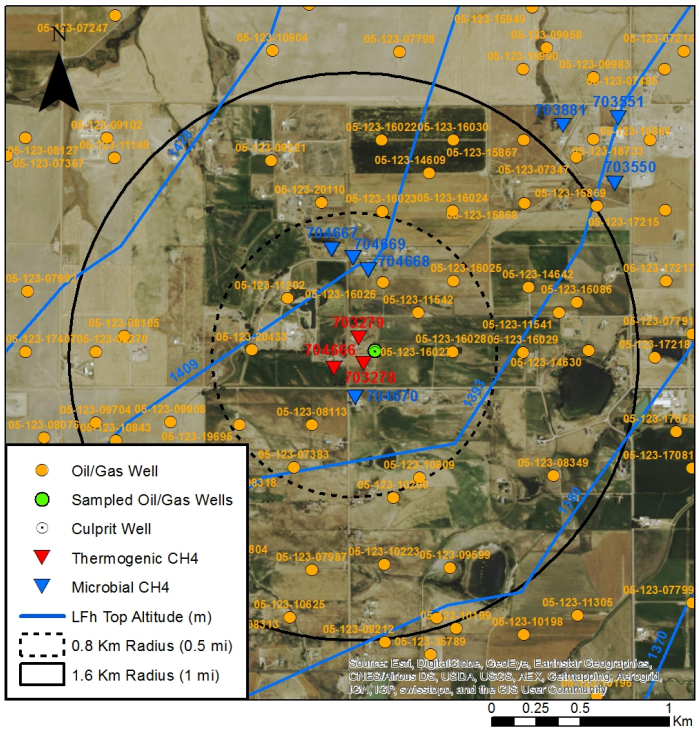

Figure S3.5 - Map view of case #5. All of the completed oil and gas wells and environmental samples collected by the COGCC are shown from the time of the incident. The altitude contour lines of the Laramie-Fox Hills aquifer demonstrate the dip of the formation.

Table S3.5 - Summary of samples collected for gas and isotope analyses in Case #5.

Facility I.D. or Well API Number	Completion Formation	Sample Date	Lab	CH_4 (mg/l)	C_1 (%)	C_2 (%)	C_3 (%)	iC_4 (%)	nC_4 (%)	$C_1/(C_2+C_3)$	$\delta^{13}C_{C1}$ (‰)	$\delta^{13}C_{C2}$ (‰)	$\delta^{13}C_{C3}$ (‰)	$\delta^{2}H_{C1}$ (‰)
Water Well														
703278	LFh	3/20/02	Isotech	n/a	61.58	3.32	1.76	0.36	0.55	12.12	-58.27	n/a	n/a	-268.3
703279	LFh	7/29/02	Isotech	n/a	66.2	7.48	3.12	0.38	0.92	6.24	-54.11	n/a	n/a	-255.5
704666	LFh	5/31/06	SevernTrent/ Isotech	10	62.97	6.03	2.64	0.38	0.76	7.26	-56.3	-33.1	n/a	-248.5
Oil&Gas Well														
05-123-16027 (prod)	Codell	6/21/02	Isotech	n/a	76.86	11.94	5.38	0.58	1.30	4.55	-47.73	n/a	n/a	-252.2

Case #6 (Unresolved, 1 water well impacted):

Complaint #200026395 was recorded with the COGCC on 5/10/2002 when a landowner reported that the quality of water in their water well (FacID # 703281) had degraded. The water well was completed in the confined Laramie-Fox Hills formation at a depth of 73 m. The COGCC first sampled the water well on 7/9/2002 and has continued to sample the well. In total, the water well has been sampled five times on 7/9/2002, 1/8/2002, 5/30/2006, 3/20/2008, and 2/26/2014. The composition and isotopic characteristics of the gas in the water well have not varied significantly with time, and all of the samples suggest that the water well has been contaminated with thermogenic gas (Table S3.6). Methane concentrations varied in the samples between 3.2 and 7.4 mg/l. Analysis of microorganisms in the samples suggested the presence of iron-related, sulfate-reducing and slime forming bacteria. No gasoline or diesel range organics were found in the impacted water well. Initially, an injection disposal well completed in the Lyons formation (API #05-123-19688) west of the impacted water well was suspected as the source of the contamination. However, the injection well was inspected in 2002 and it was determined to be structurally sound. The COGCC sampled the production gas of 6 nearby oil&gas wells: the Hambert RG 32-1 (API # 05-123-13441), the Hambert RG 32-2 (API # 05-123-13442), the Hambert R G 32-3 (API # 05-123-13443), the Hambert RG 32-6 (API# 05-123-13446), the Hambert RG 32-7 (API # 05-123-13447) and the Hambert RG 32-8 (API # 05-123-13448). All of the oil&gas wells sampled target the Niobrara and Codell formations and produce gas with similar compositions and isotopic signatures (Table S3.6). The COGCC concluded that the thermogenic gas present in the impacted water well showed signs of bacterial oxidation and its origin could not be determined. Thus the complaint is still unresolved. The landowner was advised to vent the gas in the water well and apply a disinfectant to treat the bacteria present. An overview of the complaint investigation is shown in Figure S3.6.

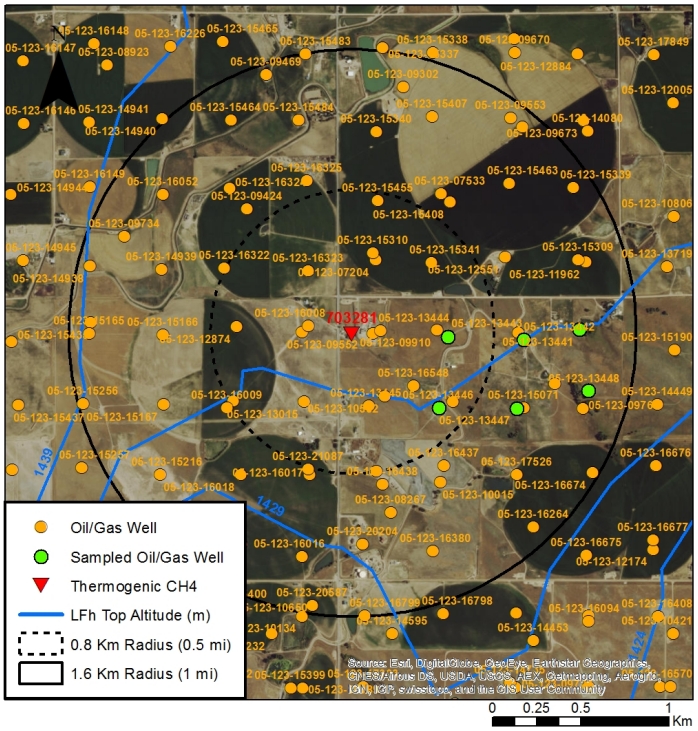

Figure S3.6 - Map view of case #6. All of the completed oil and gas wells and environmental samples collected by the COGCC are shown from the time of the incident. The altitude contour lines of the Laramie-Fox Hills aquifer demonstrate the dip of the formation.

Table S3. 6 - Summary of samples collected for gas and isotope analyses in Case #6.

Facility I.D. or Well API Number	Completion Formation	Sample Date	Lab	CH_4 (mg/l)	C_1 (%)	C_2 (%)	C_3 (%)	iC_4 (%)	nC_4 (%)	$C_1/(C_2+C_3)$	$\delta^{13}C_{C1}$ (‰)	$\delta^{13}C_{C2}$ (‰)	$\delta^{13}C_{C3}$ (‰)	$\delta^{2}H_{C1}$ (‰)
Water Well														
703281	LFh	7/9/02	Isotech	n/a	26.60	2.66	0.40	0.07	0.05	8.69	-44.39	n/a	n/a	-213.6
		1/8/04	Evergreen	6	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
		2/26/14	TestAmerica/ Isotech	7.4	18.26	2.33	0.12	0.01	0.01	7.45	-43.8	-26.7	-17.6	-213.9
Oil&Gas Well														
05-123-13441 (prod)	Niobrara/Codell	7/13/10	Isotech	n/a	77.07	11.74	4.32	0.79	1.38	4.79	-44.87	-28.14	-24.96	-217.4
05-123-13442 (prod)	Niobrara/Codell	7/13/10	Isotech	n/a	76.92	11.94	4.36	0.84	1.44	4.72	-44.06	-27.54	-24.58	-216.7
05-123-13443 (prod)	Niobrara/Codell	12/19/03	Isotech	n/a	70.67	11.97	4.66	1.96	1.23	4.25	-43.5	-27.38	n/a	-212.9

Case #7 (Settled, 1 water well impacted):

Complaint # 200030152 was recorded with the COGCC on 9/5/2002 when a landowner complained of methane gas in their water well (FacID #703282). The water well was completed in the confined Laramie-Fox Hills aquifer at a depth of 213 m. The water well was first sampled on 9/10/2002 by the COGCC. Additional samples were taken on 3/12/2003, 7/21/2004 and 3/20/2008. Isotopic and gas compositional analyses determined that a mixture of microbial and thermogenic gas was present in the well in concentrations that ranged from 3.5 mg/l to 10 mg/l between samples. No diesel or gasoline range organics were found in any of the samples. On 10/8/2002 and 10/9/2002, 15 oil&gas wells within a half mile radius of the impacted water well were tested for bradenhead pressure. The COGCC reported that no significant bradenhead pressures were found. Production gases from five nearby oil&gas wells were sampled for gas composition and isotopic signature on 11/11/2002. The samples from the impacted water well were also compared with previously collected gas isotope and compositional data from 9 nearby oil&gas wells and 7 additional nearby water wells. The COGCC determined that the stray thermogenic gas in the impacted water well was characteristic of the Sussex formation.

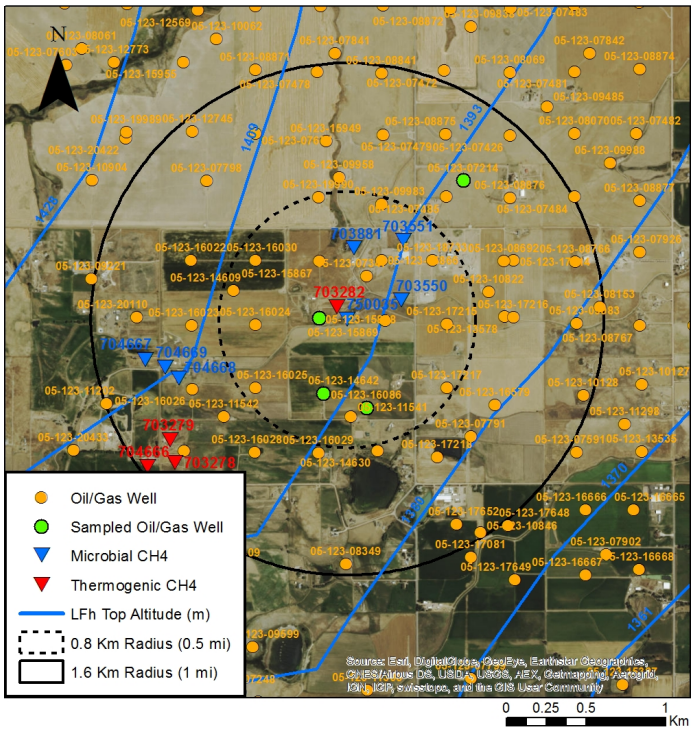

Figure S3.7 - Map view of case #7. All of the completed oil and gas wells and environmental samples collected by the COGCC are shown from the time of the incident. The altitude contour lines of the Laramie-Fox Hills aquifer demonstrate the dip of the formation.

The only nearby oil&gas well producing from the Sussex was the Schiedt State VV 16-4D (API # 05-123-16086). Gas composition and isotope analyses are shown in Table S3.7. On 5/22/2003, the Scheidt State VV 16-4D passed an MIT. However, the Scheidt State VV 16-4D, as well as a number of other nearby oil&gas wells, were found to have "suspect anomalies" in its production history. Because the Scheidt State VV 16-4D passed an MIT and showed no bradenhead pressure, the COGCC concluded that it could not identify a culprit oil&gas well and informed the landowner that they would continue to investigate the matter and sample the impacted water well. This investigation ended in September of 2008 when Noble Energy Corporation reached a private agreement with the landowners which they settled off-record. An overview of the complaint investigation is shown in Figure S3.7.

Table S3.7 - Summary of samples collected for gas and isotope analyses in Case #7.

Facility I.D. or Well API Number	Completion Formation	Sample Date	Lab	CH_4 (mg/l)	C_1 (%)	C_2 (%)	C_3 (%)	iC_4 (%)	nC_4 (%)	$C_1/(C_2+C_3)$	$\delta^{13}C_{C1}$ (‰)	$\delta^{13}C_{C2}$ (‰)	$\delta^{13}C_{C3}$ (‰)	$\delta^{2}H_{C1}$ (‰)
Water Well														
703282	LFh	9/10/02	Isotech	n/a	76.64	4.8	3.06	0.39	0.71	9.75	-56.62	n/a	n/a	-241.5
		3/20/08	Evergreen/ Isotech	10	54.77	2.09	1.66	0.31	0.47	14.6	-62.1	-33.91	n/a	-248.8
Oil&Gas Well														
05-123-16086 (prod)	Sussex	11/11/02	Isotech	n/a	80.08	7.33	4.91	0.59	1.11	6.54	-53.82	n/a	n/a	-239.7

Case #8 (Unresolved, 1 water well impacted):

On 12/9/2002, complaint #200032354 was opened with the COGCC when Glover Drilling encountered gas in a water well (FacID # 703697) that they were installing for a landowner. The well was completed in the confined Laramie-Fox Hills aquifer to a depth of 226 m. COGCC first sampled the water well on 12/12/2002. In total, six samples were collected from the water well between 12/12/2002 and 4/7/2009. All six of the water well samples found dissolved methane at concentrations between 6.8 and 16 mg/l. Gas composition and isotope analyses showed that the gas was thermogenic in origin (Table S3.8). Diesel and gasoline range organics were not detected in the water well. An older water well on the same property (FacID# 703698), also drilled into the confined Laramie-Fox Hills aquifer, was sampled five times between 1/6/2003 and 6/8/2003; compositional and isotopic analyses of the gas showed that the gas present in the older well was microbial in origin, and concentrations of methane between 3.2 and 6.3 mg/l were measured (Table S3.8). The bradenheads of eight nearby oil&gas wells were tested for pressure and no significant pressures were discovered. The production gas from two oil&gas wells within the vicinity of the contaminated well were sampled and the gas composition and isotope characteristics were determined (Table S3.8).

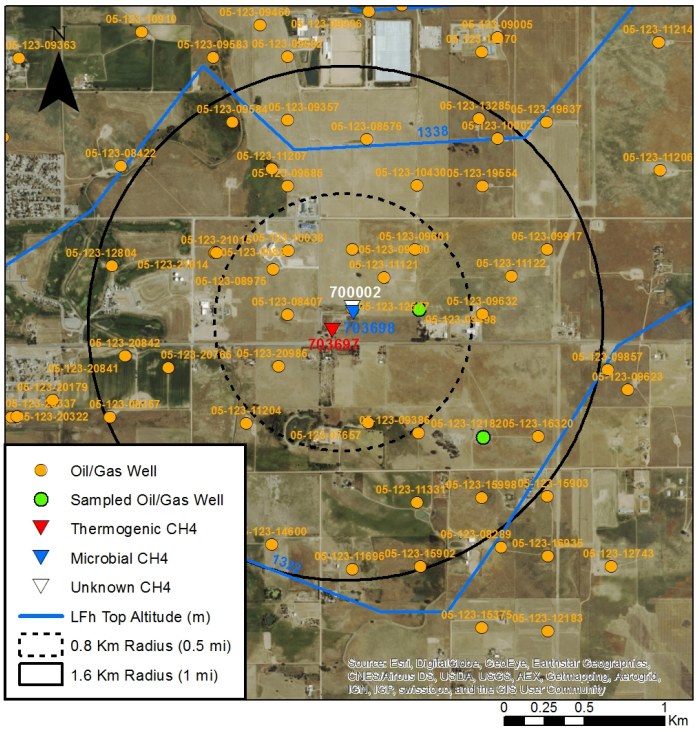

Figure S3.8 - Map view of case #8. All of the completed oil and gas wells and environmental samples collected by the COGCC are shown from the time of the incident. The altitude contour lines of the Laramie-Fox Hills aquifer demonstrate the dip of the formation.

The sample results from the thermogenic gas impacted water well were also compared with the composition and isotopic signature of gases from 10 previously sampled oil&gas wells and 4 previously sampled water wells. The COGCC concluded that the thermogenic gas contaminating the impacted water well was not related to production gas from any of the producing formations in the region. The absence of bradenhead pressures on the wells within a half mile of the impacted water well indicated that contamination from a producing well was unlikely. The low thermal maturity of the gas in the water well suggested that it originated in a shallower formation. It was hypothesized that the water well, situated in a syncline of the Laramie-Fox Hills aquifer, potentially tapped a sandstone gas trap near the base of the gas-water contact. However, it should be noted that not all of the production gases from oil&gas wells within a half mile radius of the impacted well were sampled. The COGCC never identified a culprit oil&gas well and continued to sample the impacted water well until 2009, at which point they closed the complaint. A letter from Anadarko Oil and Gas Company to the COGCC on 12/18/2009 indicated that they assisted the landowners in finding a new water source. An overview of the complaint investigation is shown in Figure S3.8.

Table S3.8 - Summary of samples collected for gas and isotope analyses in Case #8.

Facility I.D. or Well API Number	Completion Formation	Sample Date	Lab	CH_4 (mg/l)	C_1 (%)	C_2 (%)	C_3 (%)	iC_4 (%)	nC_4 (%)	$C_1/(C_2+C_3)$	$\delta^{13}C_{C1}$ (‰)	$\delta^{13}C_{C2}$ (‰)	$\delta^{13}C_{C3}$ (‰)	$\delta^{2}H_{C1}$ (‰)
Water Well														
703697	LFh	12/12/02	Isotech	n/a	70.68	16.32	6.43	0.63	1.85	3.11	-48.44	n/a	n/a	-259.5
		12/17/02	Evergreen	12	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
		5/30/06	SevernTrent/ Isotech	7.3	48.27	0.06	n/a	n/a	n/a	n/a	-73.73	n/a	n/a	-261.8
		4/7/09	Isotech	n/a	58.17	11.29	4.53	0.44	1.22	3.67	-51.47	-33.37	n/a	-261.7
703698	LFh	5/30/2006	Isotech	n/a	48.27	0.056	0.00	b.d.l.	b.d.l.	861	-73.73	n/a	n/a	n/a
Oil&Gas Well														
05-123-09498 (prod)	Sussex	3/6/03	Isotech	n/a	76.44	6.93	7.26	1.23	1.84	5.38	-56.25	n/a	n/a	-230
05-123-12182 (prod)	Nio/Cod/Suss	3/11/03	Isotech	n/a	61.17	6.58	8.39	1.84	3.88	4.08	-56.35	n/a	n/a	-230.2

Case #9 (Wellbore failure: Short surface casing and wellhead seal leak, 1 water well impacted):

Complaint #200022785 was opened with the COGCC on 12/27/2001, when a landowner's water well (FacID #703247) began producing large amounts of gas after Patina Oil and Gas Corporation hydraulically fractured and reworked a well located on their property. The landowner's water well was drilled 201 m deep and was completed in the confined Laramie Fox-Hills formation. The COGCC first collected samples from the water well on 12/28/2001 and took five additional samples between the initial sample date and 8/18/2006. There are no records of dissolved methane concentrations in the COGCC database. Evaporate and brines were identified in the impacted water well, however, no gasoline or diesel range organics were found. Gas composition and isotope analyses showed that thermogenic gas characteristic of the J-Sand formation had migrated into the well. Eleven oil&gas wells were located within one mile of the impacted water well. Of these oil&gas wells, only five were producing from the J-Sand. In total, gas samples from 7 oil&gas wells and their bradenheads were compared with the analytical results from the water well. Patina Oil and Gas Corporation discovered that the GNB 21-2J well (API # 05-123-08385), located 353 m from the impacted water well, was leaking on 1/28/2002. Upon testing, it was revealed that the bradenhead of the GNB 21-2J well had 2,068 kPag (300 psig) of pressure on 1/26/2002. The production gas of the GNB 21-2J well matched the isotopic signature and composition of the gas found in the water well (Table S3.9). This information, combined with the knowledge that the impacted water well was up gradient from the GNB 21-2J, convinced the COGCC that the GNB 21-2J well was the culprit well. Surface casing in the GNB 21-2J well was set to 210 m, a similar depth to the impacted water well (201 m) and above the bottom of the Laramie-Fox Hills formation at that location (212 m). Patina Oil and Gas Corporation was issued a NOAV on 6/19/2002. Patina remediated the GNB 21-2J well on 4/29/2002 as required by the COGCC. A flow meter, installed to measure the flow rate of gas out of the landowner's water well, registered a noticeable drop in flow rate over this time period. The landowners reached a settlement with Patina (bought by Noble Energy, Inc.), and through this acquired access to a domestic tap. Noble Energy, Inc. mailed a closure request for the NOAV and the associated remediation/complaint to the COGCC on 5/30/2007. An overview of the complaint investigation is shown in Figure S3.9.

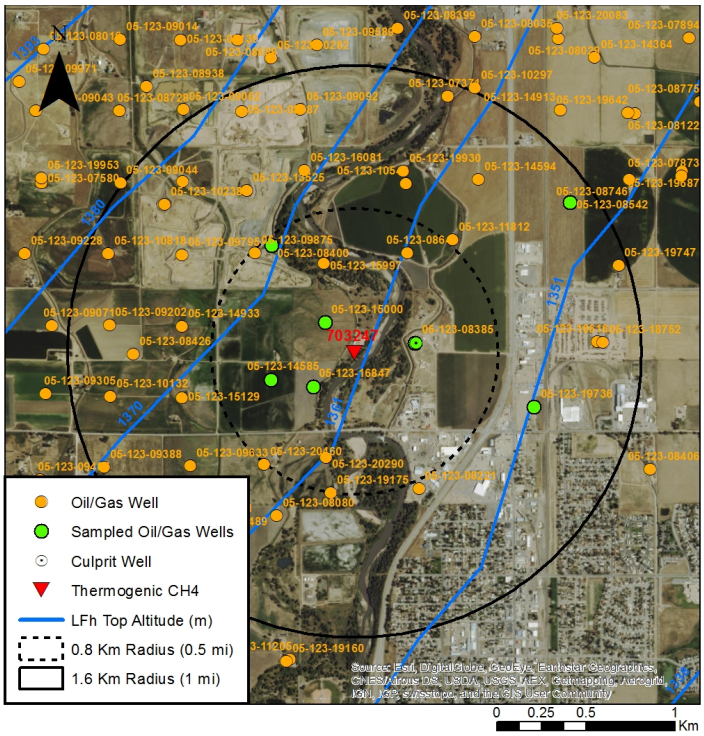

Figure S3.9- Map view of case #9. All of the completed oil and gas wells and environmental samples collected by the COGCC are shown from the time of the incident. The altitude contour lines of the Laramie-Fox Hills aquifer demonstrate the dip of the formation.

Table S3.9 - Summary of samples collected for gas and isotope analyses in Case #9.

Facility I.D. or Well API Number	Completion Formation	Sample Date	Lab	CH_4 (mg/l)	C_1 (%)	C_2 (%)	C_3 (%)	iC_4 (%)	nC_4 (%)	$C_1/(C_2+C_3)$	$\delta^{13}C_{C1}$ (‰)	$\delta^{13}C_{C2}$ (‰)	$\delta^{13}C_{C3}$ (‰)	$\delta^{2}H_{C1}$ (‰)
Water Well														
703247	LFh	12/8/01	Isotech	n/a	21.66	2.87	0.61	0.07	0.11	6.22	-47.24	n/a	n/a	-231.4
		10/10/03	Isotech	n/a	61.6	11.43	2.42	0.27	0.32	4.44	-44.72	n/a	n/a	-225.1
Oil&Gas Well														
05-123-08385 (prod)	J-Sand	12/8/01	Isotech	n/a	81.28	10.48	2.6	0.41	0.52	6.21	-47.17	n/a	n/a	-231.0

Case #10 (Wellbore failure: Short surface casing, 1 water well impacted):

Complaint #200049157 was opened with the COGCC on 1/28/2004 when a landowner reported the presence of gas and a strong rotten egg odor in their water well (FacID #704130). The water well was drilled to a depth of 11 m in the unconfined Laramie-Fox Hills aquifer. Sampling of the water well was initiated on 1/29/2004 and eight additional samples were taken between that time and 6/13/2005. The water samples contained methane at concentrations between 6.2 and 15 mg/l. Gas composition and isotope analyses indicated the presence of thermogenic gas in the water well; however, the origin of the gas has been disputed (Table S3.10). On 2/4/2004 the COGCC began investigating bradenhead pressures in oil&gas within a 0.5 mile radius. Two oil and gas wells, the Lee Gould Jr. #1 (API #05-123-07854) and the Coors Fee #2-6 (API #05-123-11060) registered significant bradenhead pressures of 965 kPag (140 psig) and 1034 kPag (150 psig), respectively. Both wells passed MIT tests conducted 2/17/2004 and 3/4/2004. Kerr McGee squeezed additional cement in bradenhead of the Lee Gould Jr #1 well on 6/29/2004 to provide cement coverage to a depth of 378 m. On 9/15/2004, analyses of a bradenhead sample from the Lee Gould Jr. #1 well (Table S3.10) showed gas with similar compositional and isotopic characteristics of the gas measured in the water well. This evidence, combined with the oil&gas well's close proximity to the impacted water well (22 m) and the fact that the Lee Gould Jr. #1 well continually built bradenhead pressure after remediation lead the COGCC to identify it as the culprit well in the investigation. On 10/19/2004, Kerr McGee was issued a NOAV for having insufficient cement coverage in the Lee Gould Jr. #1 well. Although surface casing was set to 68 m, below the modeled base of the Laramie-Fox Hills aquifer at that location (31 m), geophysical logs from two wells in adjacent sections ("Saxon" and "McCoy 1"; https://data.colorado.gov/Water/DWR-Well-Geophysical-Log/cfyk-gwjj) indicate the base of the Laramie-Fox Hills at 68 and 70 m depth. Thus, because of complex Laramie-Fox Hills stratigraphy in the area, the Lee Gould Jr. #1 well is assumed to have short surface casing. The landowners and Kerr McGee reached a settlement on 5/31/2005 and the case was closed. An overview of the complaint investigation is shown in Figure S3.10.

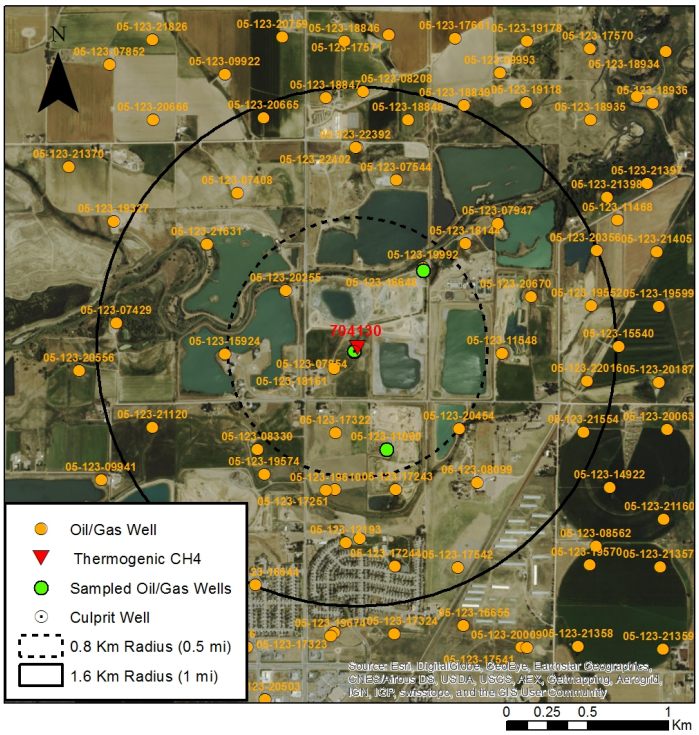

Figure S3.10 - Map view of case #10. All of the completed oil and gas wells and environmental samples collected by the COGCC are shown from the time of the incident. The altitude contour lines of the Laramie-Fox Hills aquifer demonstrate the dip of the formation.

Table S3.10 - Summary of samples collected for gas and isotope analyses in Case #10.

Facility I.D. or Well API Number	Completion Formation	Sample Date	Lab	CH_4 (mg/l)	C_1 (%)	C_2 (%)	C_3 (%)	iC_4 (%)	nC_4 (%)	$C_1/(C_2+C_3)$	$\delta^{13}C_{C1}$ (‰)	$\delta^{13}C_{C2}$ (‰)	$\delta^{13}C_{C3}$ (‰)	$\delta^{2}H_{C1}$ (‰)
Water Well														
704130	LFH	2/6/04	Isotech	n/a	80.59	10.57	2.71	0.42	0.52	6.06	-47.09	-29.58	n/a	-222.1
		4/7/05	Evergreen/ Isotech	12	74.82	13.16	4.26	0.53	1.05	4.29	-46.96	-30.77	-27.34	-224.8
Oil&Gas Well														
05-123-07854 (prod)	J-Sand	4/7/05	Isotech	n/a	81.92	9.82	2.69	0.46	0.56	0.09	-47.51	-29.88	-25.07	-222.6
05-123-07854 (annulus)	J-Sand	9/15/04	Isotech	n/a	80.68	9.65	2.87	0.55	0.66	6.44	-47.12	-29.74	n/a	-223.0

Case #11 (Wellbore failure: Short surface casing and casing leak, 1 water well impacted):

Complaint # 200051005 was opened with the COGCC on 3/9/2004 when a landowner complained that their water well (FacID # 703884) was producing black water with a hydrocarbon odor. The water well was drilled to a depth of 206 m and was completed in the Dakota-Cheyenne aquifer. A week before the complaint, Bonanza Creek Energy had begun work on the nearby (131 m offset) CEI-Gutterson #1 oil&gas well (API # 05-123-12383). Surface casing in the CEI-Gutterson #1 well was set to 92 m. The COGCC contacted Bonanza Creek on 3/9/2004 about the complaint and mentioned that remedial cement needed to be added to the CEI-Gutterson #1 to provide coverage for the deepest drinking water aquifer (between 76 m and 274 m below ground surface). During remediation, holes were found in the production casing of the CEI-Gutterson #1 at 381 m and between the depths of 232 m and 242 m. Initial sampling of the water well began on 3/11/2004 and 3/16/2004. Samples taken on 3/16/2004 were analyzed for gas composition and isotopic signature (Table S3.11) and the presence of thermogenic methane in the water well was confirmed. Benzene was found in the water samples from 3/11/2004 at a concentration of 150 µg/L, which exceeds the 5 µg/L Basic Colorado Ground Water Standard. Production and bradenhead gas samples were collected from the Lovely #1 oil and gas well and the CEI-Gutterson #1 oil and gas well on 3/12/2004. The bradenhead pressure of four nearby oil&gas wells was assessed on 3/26/2004. The gas composition and isotope analyses from the bradenhead of the CEI-Gutterson #1 well (Table S3.11) matched the characteristics of the gas present in the water well. Consequently, the COGCC issued a NOAV to Bonanza Creek on 5/17/2004 for the faulty casing and contamination of the landowner's water well. The CEI-Gutterson #1 well was repaired on 3/25/2004 and passed a MIT on 3/26/2004. There is no record of a bradenhead pressure test from before the well was remediated. Ten follow up samples of the impacted water well were taken between 6/23/2004 and 6/24/2005. Significant quantities of thermogenic gas were not detected in the water well after 6/23/2004, no BTEX was detected after the initial sampling event, and the quality of water in the well improved significantly over the sampling period. For these reasons, the COGCC closed the remediation project on 12/19/2005. An overview of the complaint investigation is shown in Figure S3.11.

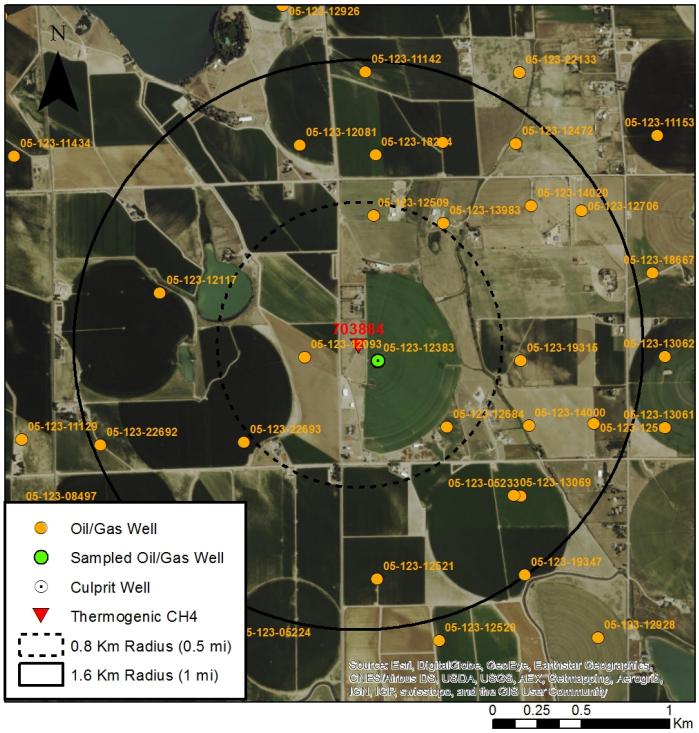

Figure S3.11 - Map view of case #11. All of the completed oil and gas wells and environmental samples collected by the COGCC are shown from the time of the incident. The altitude contour lines of the Laramie-Fox Hills aquifer demonstrate the dip of the formation.

Table S3.11 - Summary of samples collected for gas and isotope analyses in Case #11.

Facility I.D. or Well API Number	Completion Formation	Sample Date	Lab	CH_4 (mg/l)	C_1 (%)	C_2 (%)	C_3 (%)	iC_4 (%)	nC_4 (%)	$C_1/(C_2+C_3)$	$\delta^{13}C_{C1}$ (‰)	$\delta^{13}C_{C2}$ (‰)	$\delta^{13}C_{C3}$ (‰)	$\delta^{2}H_{C1}$ (‰)
Water Well														
703884	Dakota-Cheyenne	3/16/04	Isotech	n/a	63.82	0.97	0.46	0.07	0.08	44.63	-58.91	-34.5	n/a	-241.5
Oil&Gas Well														
05-123-12383 (annulus)	Codell	3/12/04	Isotech	n/a	55.92	0.82	0.50	0.18	0.16	42.36	-59.14	-34.76	n/a	-245.5

Case #12 (Unresolved, 2 water wells impacted):

On 11/30/2005, complaint # 200080649 was opened with the COGCC after a landowner reported gas in a newly drilled water well (FacID # 704597) completed in the confined Laramie-Fox Hills aquifer. The well was 142 m deep, 10 m deeper than a water well on the neighboring property (FacID #705590). Gas samples from both water wells were taken on 12/2/2005 and analyzed for gas composition and isotopic signature. Gas present in the sample taken from water well #705590 on 12/2/2005 was mixed microbial and thermogenic in origin (Table S3.12). All other samples from water well #705590 were distinctly microbial in origin. Gas measure in water well #704597 were predominately thermogenic with a smaller component of microbial methane (Table S3.12). On 12/15/2005, 5.8 mg/l of methane was measured in water well #704597. Nineteen oil&gas wells within a 0.5 mile radius of the impacted water wells were tested for bradenhead pressure. Five oil&gas wells with significant bradenhead pressures above 689.5 kPa (100 psig) were identified. Bradenhead, production casing and production tubing samples were taken from these five oil&gas wells: the gas composition and isotope analyses from the bradenheads of the three closest wells are shown in Table S3.12. The COGCC concluded that the gas in the impacted water well did not match any of the nearby oil&gas wells. Kerr McGee was issued a NOAV for the five nearby oil&gas wells with significant bradenhead pressures. Follow up samples were taken from the two water wells on 6/4/2008. Methane concentrations in water wells #704597 and #705590 were 4.7 mg/l and 4.1 mg/l, respectively. Gas composition and isotopic analyses still indicated the presence of mixed microbial and thermogenic gas in well #704597 and microbial gas in well #705590. The case has not been closed and the COGCC has not yet identified a culprit oil&gas well. An overview of the complaint investigation is shown in Figure S3.12.

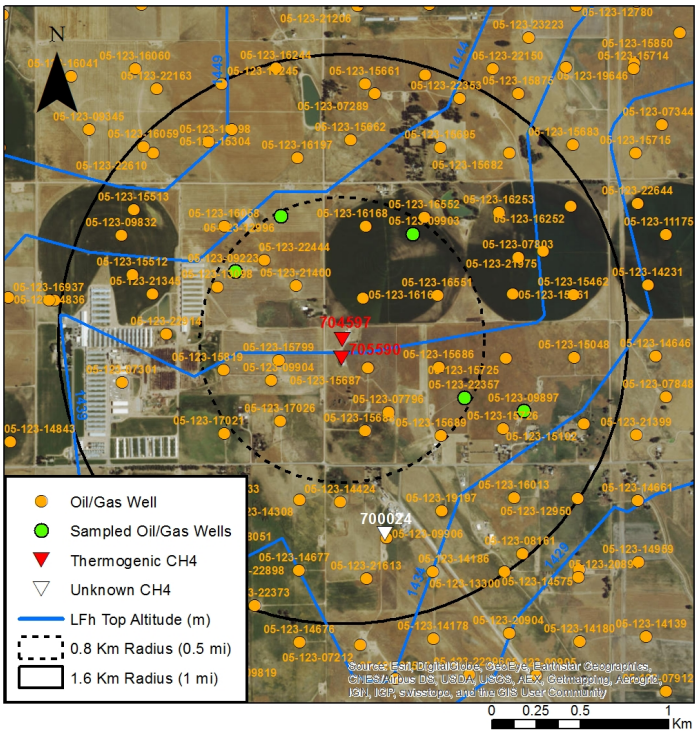

Figure S3.12 - Map view of case #12. All of the completed oil and gas wells and environmental samples collected by the COGCC are shown from the time of the incident. The altitude contour lines of the Laramie-Fox Hills aquifer demonstrate the dip of the formation.

Table S3.12 - Summary of samples collected for gas and isotope analyses in Case #12.

Facility I.D. or Well API Number	Completion Formation	Sample Date	Lab	CH_4 (mg/l)	C_1 (%)	C_2 (%)	C_3 (%)	iC_4 (%)	nC_4 (%)	$C_1/(C_2+C_3)$	$\delta^{13}C_{C1}$ (‰)	$\delta^{13}C_{C2}$ (‰)	$\delta^{13}C_{C3}$ (‰)	$\delta^{2}H_{C1}$ (‰)
Water Well														
704597	LFh	12/15/05	SevernTrent/ Isotech	5.8	74.74	5.89	2.33	0.64	0.42	9.09	-50.85	-26.86	-23.69	-221.5
705590	LFh	12/2/05	n/a	n/a	72.7	2.96	1.35	0.49	0.29	16.86	n/a	n/a	n/a	n/a
Oil&Gas Well														
05-123-09223 (annulus)	J-Sand	12/21/05	Isotech	n/a	76.99	13.53	4.24	0.62	0.94	4.33	-44.57	-27.95	-24.63	-212.1
05-123-09903 (annulus)	J-Sand	12/21/05	Isotech	n/a	79.61	12.35	4.6	0.71	1.13	4.69	-44.97	-28.17	-25.02	-214.
05-123-22357 (annulus)	Codell	12/21/05	Isotech	n/a	80.6	11.16	4.59	0.82	1.15	0.18	-46.47	-29.68	-25.08	-220.6

Case #13 (Unresolved, 1 water well impacted):

Complaint #200095126 was opened with the COGCC when the High Plains Water Users Association's (HPWUA) water well pump house caught fire on 7/26/2006. The HPWUA water well was 366 m deep and was completed in the confined Laramie-Fox Hills aquifer. Samples from the water well taken on 7/31/2006 found methane at a concentration of 12 mg/l. No BTEX was found in the sample, however, iron related bacteria were present. Gas composition and isotope analyses showed that there was a mixture of microbial and thermogenic methane in the water well (Table S3.13). The COGCC inspected the pressure on the bradenheads of 7 oil&gas wells within a 0.5 mile radius of the impacted water well and found no significant bradenhead pressures. The COGCC also reviewed well records for all of the plugged and abandoned oil&gas wells within a half mile of the HPUWA water well and found no evidence that any of the oil&gas wells would potentially release gas into a shallow aquifer. For these reasons, the COGCC did not sample any nearby oil&gas wells and did not issue any operators a NOAV. This case is still open and unresolved. An overview of the complaint investigation is shown in Figure S3.13.

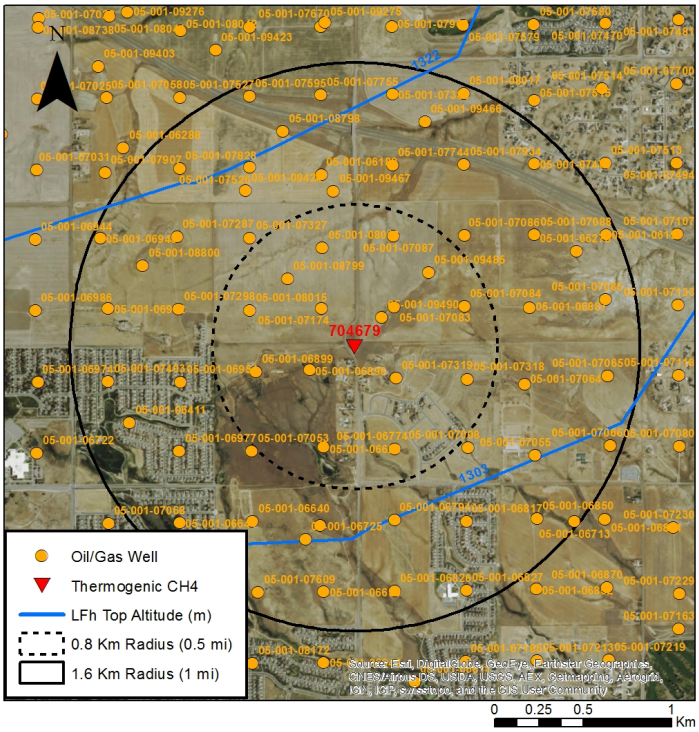

Figure S3.13 - Map view of case #13. All of the completed oil and gas wells and environmental samples collected by the COGCC are shown from the time of the incident. The altitude contour lines of the Laramie-Fox Hills aquifer demonstrate the dip of the formation.

Table S3.13 - Summary of samples collected for gas and isotope analyses in Case #13.

Facility I.D. or Well API Number	Completion Formation	Sample Date	Lab	CH_4 (mg/l)	C_1 (%)	C_2 (%)	C_3 (%)	iC_4 (%)	nC_4 (%)	$C_1/(C_2+C_3)$	$\delta^{13}C_{C1}$ (‰)	$\delta^{13}C_{C2}$ (‰)	$\delta^{13}C_{C3}$ (‰)	$\delta^{2}H_{C1}$ (‰)
Water Well														
704679	LFh	7/31/06	SevernTrent/ Isotech	12	54.65	0.39	0.30	0.06	0.05	79.2	-68.49	n/a	-32.44	-230.7

Case #14 (Unresolved, 1 water well impacted):

Complaint #200101991 was opened with the COGCC on 1/5/2007 when baseline sampling identified gas present in a landowner's water well (FacID #705016). The water well was completed in the confined Laramie-Fox Hills aquifer at a depth of 98 m. Initial samples were taken from the water well on 6/15/2006 and 9/14/2006. Methane concentrations in the water well ranged between 14.4 mg/l on 6/15/2006 and 30 mg/l on 9/14/2006. Gas composition and isotope analyses indicated that the methane in the water well was of a thermogenic origin (Table S3.14). The COGCC inspected the bradenheads of 20 oil&gas wells within a 0.5 mile radius of the impacted water well. Six of the 20 oil&gas wells had significant bradenhead pressures above 689.5 kPag (100 psig). Gas samples were collected from the production tubing and bradenheads of the six nearby oil&gas wells (Table S3.14). None of the six sampled bradenheads contained gas with compositional and isotopic characteristics similar to the gas in the impacted water well. As a result, the COGCC did not identify a culprit oil&gas well and no NOAVs were issued. Follow-up sampling on confirmed that thermogenic gas was still present in the contaminated water well on 6/9/2014. This complaint is still open and unresolved. An overview of the complaint investigation is shown in Figure S3.14.

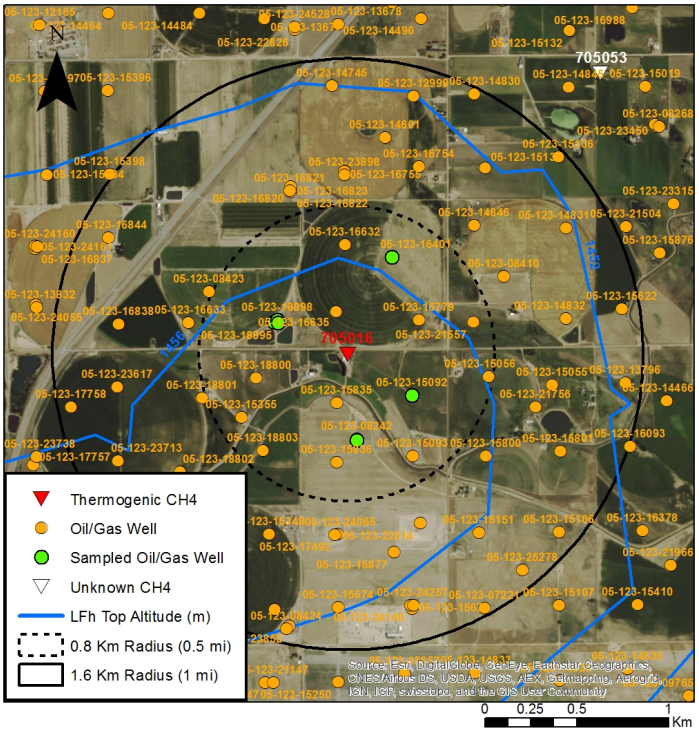

Figure S3.14 - Map view of Case #14. All of the completed oil and gas wells and environmental samples collected by the COGCC are shown from the time of the incident. The altitude contour lines of the Laramie-Fox Hills aquifer demonstrate the dip of the formation.

Table S3.14 - Summary of samples collected for gas and isotope analyses in Case #14.

Facility I.D. or Well API Number	Completion Formation	Sample Date	Lab	CH_4 (mg/l)	C_1 (%)	C_2 (%)	C_3 (%)	iC_4 (%)	nC_4 (%)	$C_1/(C_2+C_3)$	$\delta^{13}C_{C1}$ (‰)	$\delta^{13}C_{C2}$ (‰)	$\delta^{13}C_{C3}$ (‰)	$\delta^{2}H_{C1}$ (‰)
Water Well														
705016	LFh	9/14/06	TestAmerica/ Isotech	14.4	66.74	4.09	1.88	0.60	0.34	11.17	-51.07	-27.42	-24.37	-217.6
		6/15/07	Isotech	12	73.92	5.44	2.20	.62	.39	9.67	-48.43	-27.57	n/a	-219.0
Oil&Gas Well														
05-123-16401 (annulus)	J-Sand/Nio/Cod	6/7/2007	Isotech	n/a	69.26	15.22	10.14	1.35	1.97	2.73	-49.14	-34.42	n/a	-231.1
05-123-15092 (annulus)	J-Sand/Codell	6/7/2007	Isotech	n/a	75.40	10.90	4.79	0.67	1.11	4.8	-47.23	-31.54	n/a	-228
05-123-08242 (annulus)	J-Sand	6/7/2007	Isotech	n/a	78.20	13.29	4.33	0.71	1.16	4.43	-44.77	-27.21	n/a	-217.5
05-123-18895 (annulus)	Niobara/Codell	6/7/2007	Isotech	n/a	71.49	10.88	2.80	0.42	0.54	5.22	-44.14	-27.22	n/a	-212.1
05-123-18898 (annulus)	Niobara/Codell	6/7/2007	Isotech	n/a	74.92	13.82	4.78	0.81	1.40	4.02	-44.66	-28.55	n/a	-214.7
05-123-16634 (annulus)	J-Sand/Nio/Cod	6/7/2007	Isotech	n/a	80.22	10.60	2.98	0.48	0.77	5.91	-45.74	-28.66	n/a	-210.7

Case #15 (Wellbore failure: Short surface casing and casing leak, 1 water well impacted):

A landowner filed complaint #200097544 with the COGCC on 10/5/2006 after observing vigorous gas bubbling in their water well (FacID #704769). The water well was completed in the Arapahoe aquifer at a depth of 122 m. Noble Energy was contacted because they operated the Wailes 41-33 1-X well (API # 05-001-07626), located approximately 103 m away from the water well. Upon inspection, the bradenhead of the Wailes 41-33-X well registered 689.5 kPag (100 psig) of pressure. Integrity testing revealed the presence of one or more leaks in the production casing of the Wailes 41-33-X well. The gas from the bradenhead of the Wailes 41-33-X well was sampled on 10/5/2006. Gas samples were also taken from the water well on 10/6/2006. Methane was found in the landowner's water well at a concentration of 6.46 mg/l. Benzene was detected in the sample taken on 10/6/2006, however, it was determined to be a false positive after no benzene was found in a sample taken from the water well on 10/20/2006. Gas composition and isotope analyses indicated that the gas in the water well (Table S3.15) was thermogenic and characteristic of the J-Sand formation. The gas from the Wailes 41-33-X well (Table S3.15) was compositionally and isotopically similar to the gas in the water well. Surface casing in the Wailes 41-33-X well was set to 65 m, shallower than the depth of the impacted water well. This evidence was sufficient enough for the COGCC to issue Noble Energy a Notice of Alleged Violation on 12/5/2006. The impacted water well was sampled 7 times between 10/6/2006 and 6/28/2007. Over that time period the methane concentrations dropped from 6.46 mg/l to 0.0017 mg/l. The complaint investigation was closed on 2/28/2009. However, the landowner reported to continue to experience skin rashes from the water. A new well was drilled for the landowner on 6/30/2009. Analytical results revealed very low levels of methane in the new well of 0.0033 mg/l, which are well below the COGCC threshold of concern (2.0 mg/l). An overview of the complaint investigation is shown in Figure S3.15.

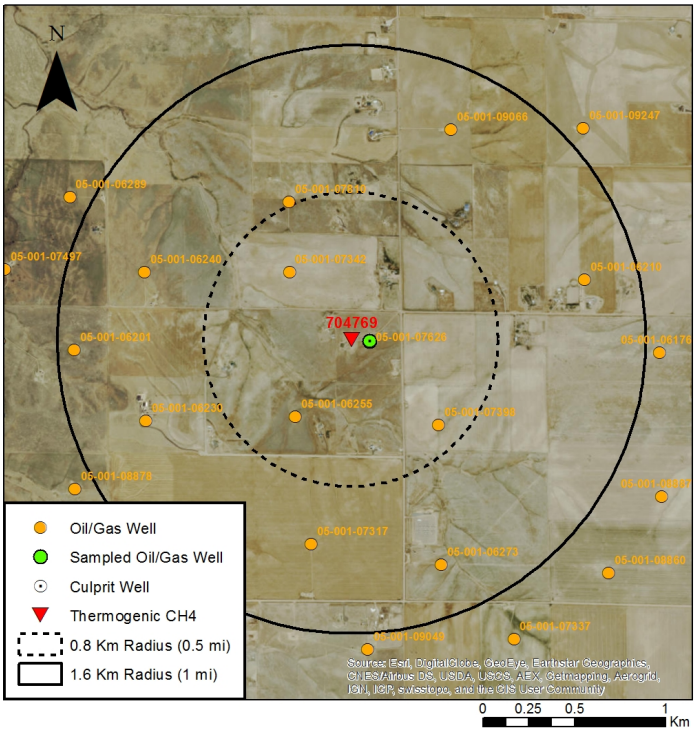

Figure S3.15 - Map view of Case #15. All of the completed oil and gas wells and environmental samples collected by the COGCC are shown from the time of the incident. The altitude contour lines of the Laramie-Fox Hills aquifer demonstrate the dip of the formation.

Table S3.15- Summary of samples collected for gas and isotope analyses in Case #15.

Facility I.D. or Well API Number	Completion Formation	Sample Date	Lab	CH_4 (mg/l)	C_1 (%)	C_2 (%)	C_3 (%)	iC_4 (%)	nC_4 (%)	$C_1/(C_2+C_3)$	$\delta^{13}C_{C1}$ (‰)	$\delta^{13}C_{C2}$ (‰)	$\delta^{13}C_{C3}$ (‰)	$\delta^{2}H_{C1}$ (‰)
Water Well														
704769	Arapahoe	10/6/06	ESN/Isotech	6.46	67.19	14.84	5.23	0.551	1.29	3.34	-49.11	-32.87	-28.35	-248.9
Oil&Gas Well														
05-001-07626 (Annulus)	J-Sand	10/5/06	Isotech	n/a	64.37	12.34	4.91	0.69	1.30	3.73	-49.33	-32.91	-28.35	-245.3

Case #16 (Unresolved, 1 water well impacted):

On 8/7/2007, a baseline sample collected by the COGCC measured 1.5 mg/l of methane in a landowner's water well (FacID #705037). The well was completed in the Arapahoe aquifer at a depth of 122 m. Gas composition and isotope analyses indicate that the gas measured in the water well was of a thermogenic origin. No complaint was opened with the COGCC and no documents were available detailing an investigation. Figure S3.16 portrays the impacted water well and the surrounding region.

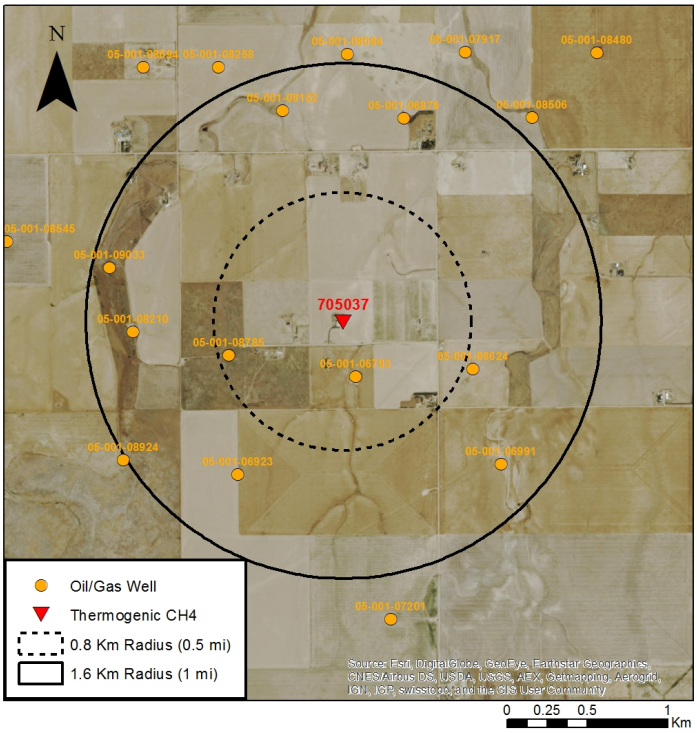

Figure S3.16 - Map view of Case #16. All of the completed oil and gas wells and environmental samples collected by the COGCC are shown from the time of the incident. The altitude contour lines of the Laramie-Fox Hills aquifer demonstrate the dip of the formation.

Table S3.16- Summary of samples collected for gas and isotope analyses in Case #16.

Facility I.D. or Well API Number	Completion Formation	Sample Date	Lab	CH_4 (mg/l)	C_1 (%)	C_2 (%)	C_3 (%)	iC_4 (%)	nC_4 (%)	$C_1/(C_2+C_3)$	$\delta^{13}C_{C1}$ (‰)	$\delta^{13}C_{C2}$ (‰)	$\delta^{13}C_{C3}$ (‰)	$\delta^{2}H_{C1}$ (‰)
Water Well														
705037	Arapahoe	6/12/07	n/a	1.5	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
		8/27/07	Isotech	n/a	13.07	2.20	n/a	n/a	n/a	5.94	-46.16	-30.53	n/a	-220.2

Case #17 (Settled, 1 water well impacted):

Complaint # 200196553 was opened with the COGCC on 9/18/2008 when a landowner complained about the presence of gas in their water well (FacID # 705592. The water well was completed in the confined Laramie-Fox Hills aquifer at a depth of 209 m. The COGCC first sampled the water well on 9/22/2008 and found methane at a concentration of 26 mg/l. "Aggressive" levels of iron-related and sulfate-reducing bacteria were reported in the water well. Gas composition and isotope analyses indicated that the methane in the water well was of a thermogenic origin (Table S3.17). A sample of the water well was taken on 2/20/2009 showed methane at a concentration of 38 mg/l. Well construction and completion records for 37 oil&gas wells within a 1 mile radius of the impacted water well were investigated by the COGCC. Nine oil&gas wells within a 0.5 mile radius did not register a bradenhead pressure on 10/15/2008. In March of 2009 all nine oil&gas wells underwent mechanical integrity tests and passed, which indicated that they were structurally sound. The COGCC concluded that there were no active leaks within a 0.5 mile radius of the water well, however, they did not rule out the potential for older leaks to have caused the contamination. Between 10/22/2008 and 4/7/2009 the COGCC collected production gas samples from the nine oil&gas wells within a 0.5 mile radius of the well for gas composition and isotope analysis. Unfortunately, these samples were not available in the COGCC's online database, however, it was noted in a summary document that no nearby oil&gas wells were producing gas with compositional and isotopic characteristics similar to the gas present in the impacted water well. Twenty-six nearby water wells were tested by the COGCC and no thermogenic gas was detected in any of the samples. On 3/21/2009, the impacted water well was disconnected and Noble Energy Company began providing substitute water for the landowners. Noble Energy Company reached an agreement with the landowners on 6/17/2009 which stated that a filter would be provided for the impacted well and any additional issues would be settled confidentially. The COGCC closed the complaint investigation on 8/7/2009 and an overview is shown in Figure S3.17.

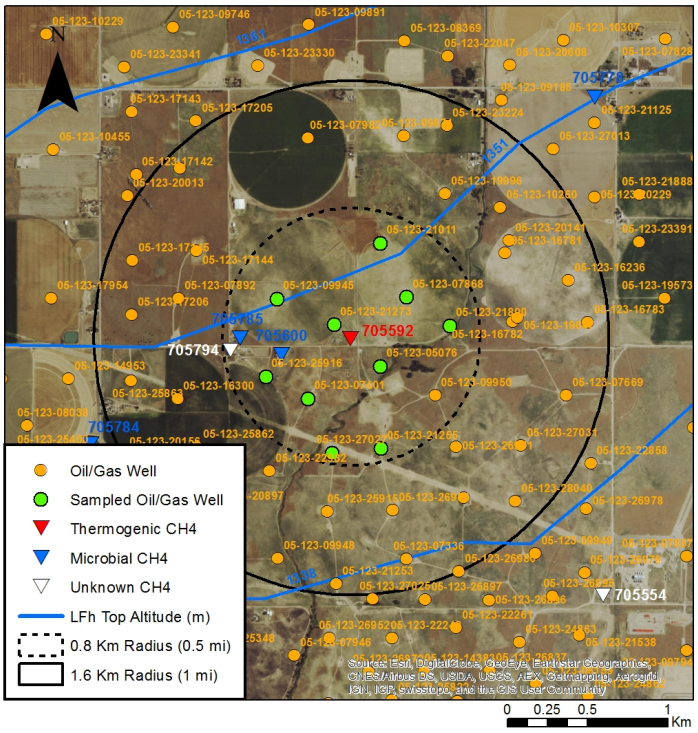

Figure S3.17 - Map view of Case #17. All of the completed oil and gas wells and environmental samples collected by the COGCC are shown from the time of the incident. The altitude contour lines of the Laramie-Fox Hills aquifer demonstrate the dip of the formation.

Table S3.17 -Summary of samples collected for gas and isotope analyses in Case #17.

Facility I.D. or Well API Number	Completion Formation	Sample Date	Lab	CH_4 (mg/l)	C_1 (%)	C_2 (%)	C_3 (%)	iC_4 (%)	nC_4 (%)	$C_1/(C_2+C_3)$	$\delta^{13}C_{C1}$ (‰)	$\delta^{13}C_{C2}$ (‰)	$\delta^{13}C_{C3}$ (‰)	$\delta^{2}H_{C1}$ (‰)
Water Well														
705592	LFh	9/22/08	TestAmerica/ Isotech	26	77.87	8.37	3.71	0.42	0.98	6.45	-55.33	-33.49	-29.27	-251.5
		2/20/09	Isotech	n/a	79.02	8.52	3.84	0.46	1.02	6.39	-54.9	-33.5	-29.33	-259.2

Case #18 (Unresolved, 1 water well impacted):

On 11/10/2008, the COGCC sampled a landowner's water well (FacID #705573) and found 11 mg/l of methane. The water well was drilled to 219 m into the confined Laramie-Fox Hills aquifer. Gas composition and isotope analyses indicate that the gas observed in the water well was of a thermogenic origin. No complaint was opened with the COGCC and no documents were available detailing an investigation. Figure S3.18 portrays the impacted water well and the surrounding region.

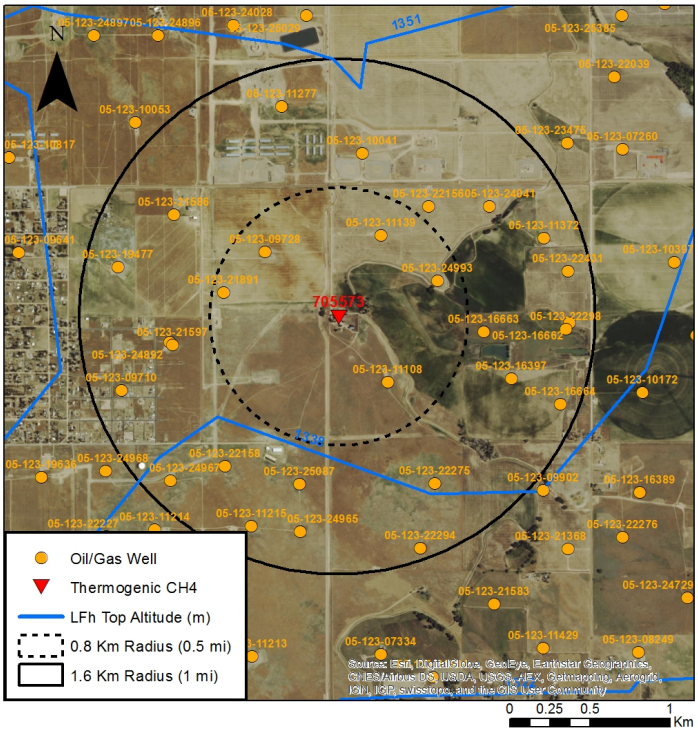

Figure S3.18 - Map view of Case #18. All of the completed oil and gas wells and environmental samples collected by the COGCC are shown from the time of the incident. The altitude contour lines of the Laramie-Fox Hills aquifer demonstrate the dip of the formation.

Table S3.18 - Summary of samples collected for gas and isotope analyses in Case #18.

Facility I.D. or Well API Number	Completion Formation	Sample Date	Lab	CH_4 (mg/l)	C_1 (%)	C_2 (%)	C_3 (%)	iC_4 (%)	nC_4 (%)	$C_1/(C_2+C_3)$	$\delta^{13}C_{C1}$ (‰)	$\delta^{13}C_{C2}$ (‰)	$\delta^{13}C_{C3}$ (‰)	$\delta^{2}H_{C1}$ (‰)
Water Well														
705573	LFh	11/10/08	Evergreen/ Isotech	11	66.96	1.01	0.313	0.04	0.06	50.61	-69.72	n/a	-28.09	-269.7

Case #19 (Unresolved, 1 water well impacted):

This case involves a complaint (# 200003296) opened on 2/8/2000 because of a flowline leak reported on a landowner's property southeast of the Clifford L3-3 (API # 123-15286) and Clifford L3-6 oil and gas wells (API # 05-123-15289). The landowner reported that a flowline ruptured which resulted in the contamination of one acre with hydrocarbons. The flowline was broken for at least six months and corn planted on the land was killed. The COGCC collected soil samples and no "significant environmental impact" was found. Subsequently, a new complaint file (# 200311007) was opened on 5/25/2011 after baseline sampling identified thermogenic methane in the landowner's house water well (FacID # 752407). The water well, drilled to 91 m depth in the confined Laramie-Fox Hills aquifer, contained dissolved methane at concentrations of up to 17 mg/l and tested positive for thermogenic methane (Table S3.19). A sample from a nearby stock water well (FacID # 752407), drilled to 22 m in the confined Laramie-Fox Hills aquifer was measured with only 0.002 mg/l dissolved methane (Table S3.19). Complaint # 200311007 is still open with the COGCC and no documents were available in the online database that suggest further investigation has occurred. An overview of the complaint investigation is shown in Figure S3.19.

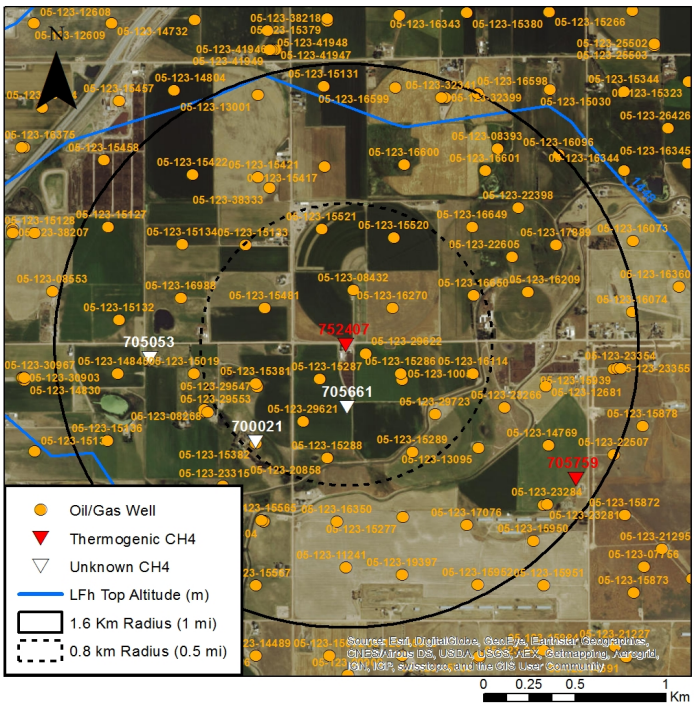

Figure S3.19 - Map view of Case #19. All of the completed oil and gas wells and environmental samples collected by the COGCC are shown from the time of the incident. The altitude contour lines of the Laramie-Fox Hills aquifer demonstrate the dip of the formation.

Table S3.19 - Summary of samples collected for gas and isotope analyses in Case #19.

Facility I.D. or Well API Number	Completion Formation	Sample Date	Lab	CH_4 (mg/l)	C_1 (%)	C_2 (%)	C_3 (%)	iC_4 (%)	nC_4 (%)	$C_1/(C_2+C_3)$	$\delta^{13}C_{C1}$ (‰)	$\delta^{13}C_{C2}$ (‰)	$\delta^{13}C_{C3}$ (‰)	$\delta^{2}H_{C1}$ (‰)
Water Well														
752407 (house)	LFh	6/30/09	Isotech	17.0	79.08	9.91	3.96	0.72	0.99	5.70	-46.08	n/a	-23.97	-214.9
		7/24/09	Empact	n/a	78.92	9.48	3.16	0.50	0.83	6.24	n/a	n/a	n/a	n/a
		7/30/09	Isotech/ Evergreen	16.0	76.99	8.64	3.33	0.59	0.84	6.43	n/a	n/a	n/a	n/a
705661 (stock)	LFh	7/30/09	Evergreen	0.002	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Case #20 (Unresolved, 1 water well impacted):

On 10/16/2009, complaint # 200220190 was opened with the COGCC when Kerr McGee/Anadarko reported finding gas present in a water well (FacID # 705759). The water well was completed in the confined Laramie-Fox Hills aquifer at a depth of 112 m. The landowner requested a sample be taken from their water well because of hydrocarbon odors. A water sample taken on 8/10/2009 had methane at a concentration of 9.4 mg/l. Gas composition and isotopic analyses indicated the presence of thermogenic methane in the water well. Complaint # 200311007 is still open with the COGCC and no documents were available in the online database that suggest further investigation has occurred. An overview of the complaint investigation is shown in Figure S3.20.

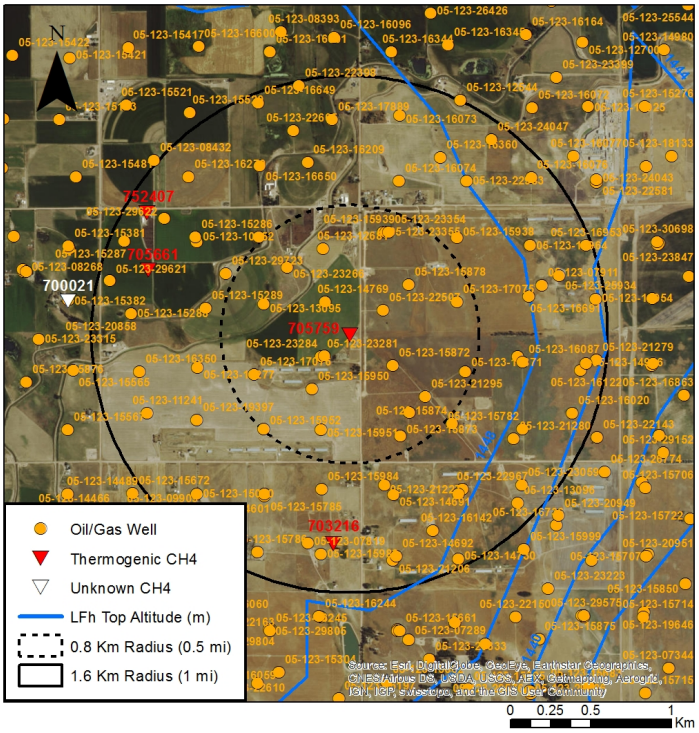

Figure S3.20 - Map view of Case #20. All of the completed oil and gas wells and environmental samples collected by the COGCC are shown from the time of the incident. The altitude contour lines of the Laramie-Fox Hills aquifer demonstrate the dip of the formation.

Table S3.20 - Summary of samples collected for gas and isotope analyses in Case #20.

Facility I.D. or Well API Number	Completion Formation	Sample Date	Lab	CH_4 (mg/l)	C_1 (%)	C_2 (%)	C_3 (%)	iC_4 (%)	nC_4 (%)	$C_1/(C_2+C_3)$	$\delta^{13}C_{C1}$ (‰)	$\delta^{13}C_{C2}$ (‰)	$\delta^{13}C_{C3}$ (‰)	$\delta^{2}H_{C1}$ (‰)
Water Well														
705759	LFh	8/10/09	Evergreen/ Isotech	9.4	34.54	4.35	1.86	0.22	0.29	5.56	-51.56	n/a	-27.31	-234.6

Case #21 (Wellbore failure: Short surface casing and casing, 1 water well impacted):

Complaint # 200217527 was opened with the COGCC on 9/1/2009 when a landowner reported concerned of possible contamination in their newly installed water well (FacID # 705746). The water well was completed in the confined Laramie-Fox Hills aquifer at a depth of 37 m. A gas sample from the water well taken on 8/11/2009 contained 17 mg/l of methane. Gas composition and isotope analyses indicated that the gas was thermogenic in origin (Table S3.21). Toluene was also detected in the well at 12 µg/L. The COGCC inspected the bradenheads of all of the oil&gas wells within a 0.5 mile radius of the impacted water well for elevated pressure. A bradenhead test on 10/1/2009 found 1655 kPag (240 psig) of pressure on the bradenhead of the Dupper # 2 well (API #05-123-11848). Eddy Oil Company was issued a Notice of Alleged violation immediately after failing the bradenhead test. The COGCC collected a gas sample from the bradenhead from the Dupper #2 well on the same day as the bradenhead test. The gas present in the bradenhead of the Dupper #2 well was thermogenic and had the same compositional and isotopic characteristics of the gas present in the impacted water well (Table S3.21). The Dupper #2 well failed a mechanical integrity test, and upon further inspection holes in the casing were found. Surface casing in the Dupper #2 well was set to 103 m, which was above the bottom of the Laramie-Fox Hills formation at that location (109 m). The Dupper #2 well was also in close proximity to the impacted water well (307 m offset). The COGCC issued Eddy Oil Company a NOAV on 11/17/2009 for contaminating the landowner's water well and required Eddy Oil to provide an alternative source of potable water. The Dupper #2 well was plugged and abandoned on 2/21/2010 the case was closed on 9/3/2010. An overview of the complaint investigation is shown in Figure S3.21.

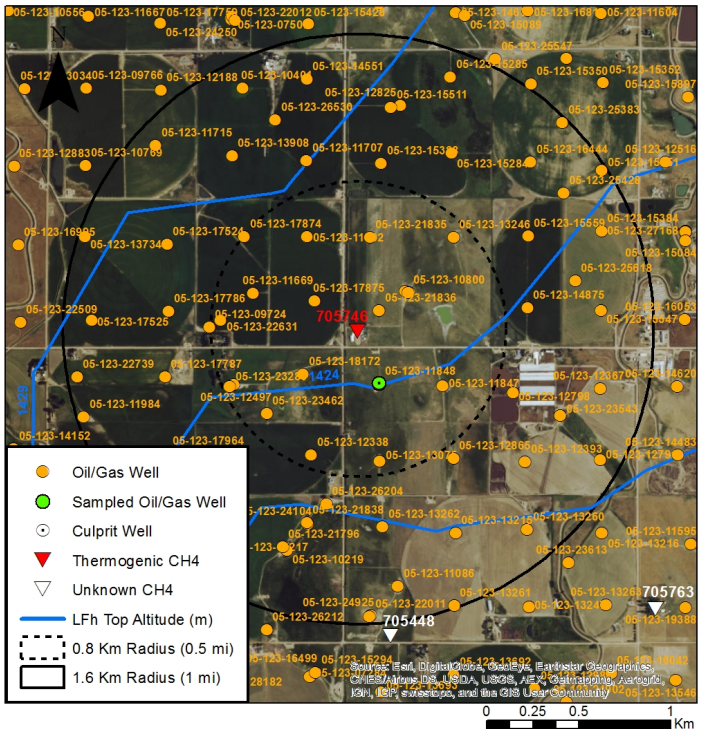

Figure S3.21 - Map view of Case #21. All of the completed oil and gas wells and environmental samples collected by the COGCC are shown from the time of the incident. The altitude contour lines of the Laramie-Fox Hills aquifer demonstrate the dip of the formation.

Table S3.21 - Summary of samples collected for gas and isotope analyses in Case #21.

Facility I.D. or Well API Number	Completion Formation	Sample Date	Lab	CH_4 (mg/l)	C_1 (%)	C_2 (%)	C_3 (%)	iC_4 (%)	nC_4 (%)	$C_1/(C_2+C_3)$	$\delta^{13}C_{C1}$ (‰)	$\delta^{13}C_{C2}$ (‰)	$\delta^{13}C_{C3}$ (‰)	$\delta^{2}H_{C1}$ (‰)
Water Well														
705746	LFh	8/11/09	Evergreen/ Isotech	17	74.92	9.14	4.05	0.49	0.63	5.68	-49.13	-28.65	-26.41	-228.4
Oil&Gas Well														
05-123-11848 (annulus)	Codell	10/9/09	Isotech	n/a	50.02	8.51	11.31	3.78	7.42	2.52	-48.88	-29.83	n/a	-228.4

Case #22 (Unresolved, 1 water well impacted):

Complaint # 200271009 was opened on 9/13/2010 following the identification of thermogenic methane in a water well (FacID # 703539) during baseline sampling. The sample was collected from the landowner's well on 2/18/2010. The water well was drilled to a depth of 162 m and completed in the confined Laramie-Fox Hills aquifer. Gas composition and isotope analyses show that the gas in the water well was thermogenic (Table S3.22). The construction details of the Kerr McGee/Anadarko wells within a half of a mile of the impacted water well were inspected and bradenhead pressure tests were performed. While some oil and gas wells registered bradenhead pressures, most of them were new and had sufficient casing to protect drinking water aquifers. Complaint #200311007 is still open with the COGCC and no additional documents were available in the online database that suggest further investigation has occurred. An overview of the complaint investigation is shown in Figure S3.22.

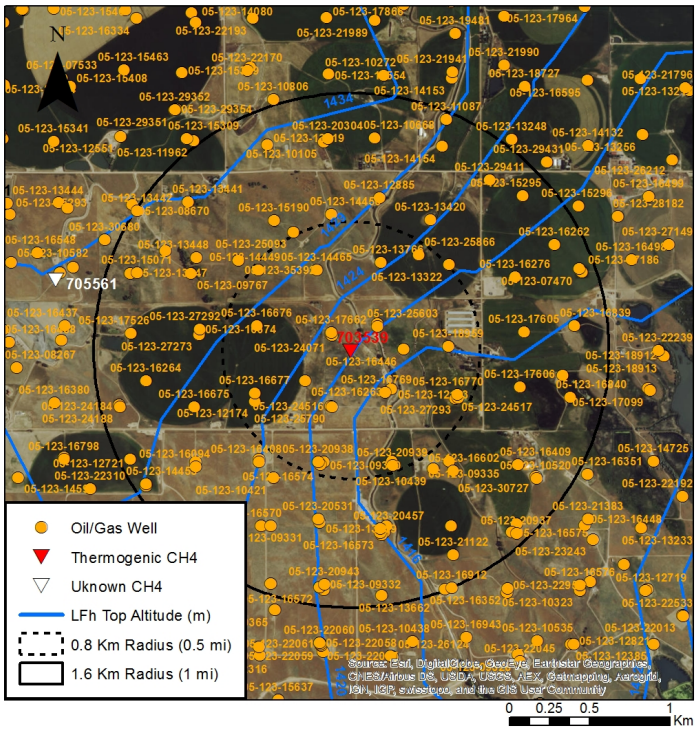

Figure S3.22 - Map view of Case #22. All of the completed oil and gas wells and environmental samples collected by the COGCC are shown from the time of the incident. The altitude contour lines of the Laramie-Fox Hills aquifer demonstrate the dip of the formation.

Table S3.22 - Summary of samples collected for gas and isotope analyses in Case #22.

Facility I.D. or Well API Number	Completion Formation	Sample Date	Lab	CH_4 (mg/l)	C_1 (%)	C_2 (%)	C_3 (%)	iC_4 (%)	nC_4 (%)	$C_1/(C_2+C_3)$	$\delta^{13}C_{C1}$ (‰)	$\delta^{13}C_{C2}$ (‰)	$\delta^{13}C_{C3}$ (‰)	$\delta^{2}H_{C1}$ (‰)
Water Well														
703539	LFh	2/18/10	Accutest/ Isotech	n/a	89.70	6.6	2.1	0	0.7	10.31	-54.30	n/a	n/a	n/a

Case #23 (Unresolved, 1 water well impacted):

Complaint #200271005 was reported in 2010 by Noble Energy after thermogenic gas was measured in a private water well (FacID # 752670) during baseline monitoring. The water well was completed in the confined Laramie-Fox Hills aquifer at a depth of 130 m. The baseline sample collected had a methane concentration of 12.9 mg/l and high concentrations of C_2+ alkanes, characteristic of thermogenic gas (Table S3.23). Production gas from 13 nearby oil&gas wells were sampled and analyzed: results from the three nearest production wells are included in Table S3.23. Based on compositional, $\delta^{13}C_{C1}$, $\delta^{13}C_{C2\text{-}C3}$ and $\delta^{2}H_{C1}$ results, no apparent source was identified for the thermogenic gas observed in the water well. The gas observed in the water well was less thermally mature than the production gas from the J Sand, Codell and Niobrara oil and gas wells, suggesting that the gas in the water well originated from a shallower thermogenic gas-bearing interval, such as the Sussex. There were no reported subsequent samples collected from the private water well. The case was considered unresolved. An overview of the complaint investigation is shown in Figure S3.23.

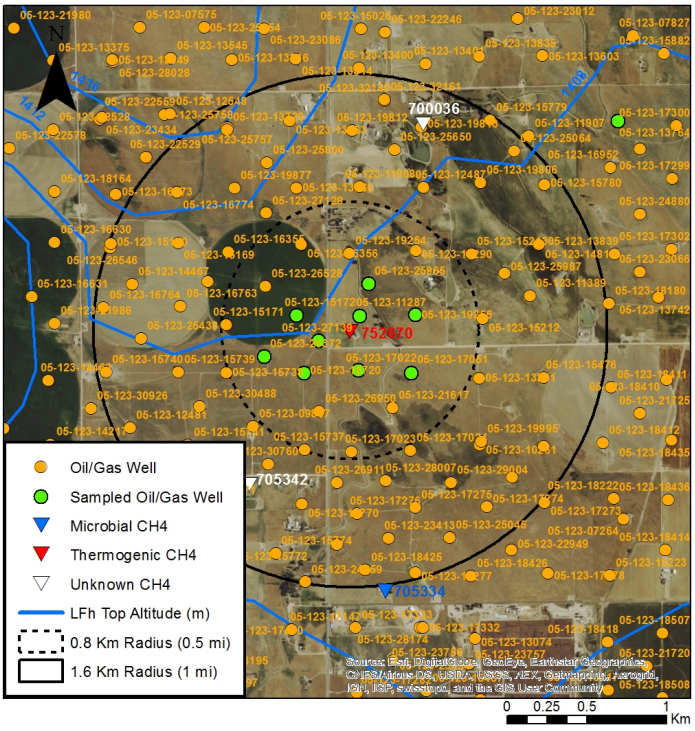

Figure S3.23 - Map view of Case #23. All of the completed oil and gas wells and environmental samples collected by the COGCC are shown from the time of the incident. The altitude contour lines of the Laramie-Fox Hills aquifer demonstrate the dip of the formation.

Table S3.23 - Summary of samples collected for gas and isotope analyses in Case #23.

Facility I.D. or Well API Number	Completion Formation	Sample Date	Lab	CH_4 (mg/l)	C_1 (%)	C_2 (%)	C_3 (%)	iC_4 (%)	nC_4 (%)	$C_1/(C_2+C_3)$	$\delta^{13}C_{C1}$ (‰)	$\delta^{13}C_{C2}$ (‰)	$\delta^{13}C_{C3}$ (‰)	$\delta^{2}H_{C1}$ (‰)
Water Well														
752670	LFh	4/30/10	Accutest/ Isotech	12.9	73.03	8.06	4.77	0.78	1.18	5.69	-51.47	-30.56	-28.42	-233.2
Oil&Gas Well														
05-123-11287 (prod)	Cod/Nio/Suss	7/14/10	Isotech	n/a	74.91	12.03	5.56	1.01	1.95	4.26	-46.98	-30.07	-27.27	-231.3
05-123-27139 (prod)	Cod/Nio /J-Sand	7/14/10	Isotech	n/a	76.11	11.76	4.72	0.871	1.59	4.62	-44.89	-29.2	-26.31	-220.5
05-123-17022 (prod)	Cod/Nio/Suss	7/14/10	Isotech	n/a	69.89	12.42	4.54	0.641	1.05	4.12	-43.97	-29.22	-26.27	-226.9

Case #24 (Wellbore failure: Short surface casing and casing leak, 2 water wells impacted):

Complaint #200276485 was recorded on 9/13/2010 when methane was reported in a water well (FacID #750159). The water well was completed in the confined Laramie-Fox Hills aquifer at a depth of 122 m. Gas composition and isotope analyses from a sample collected on 9/23/10 indicated the presence of thermogenic gas (Table S3.24). Methane concentrations were not measured in the water well at that time and BTEX compounds were not detected. The thermogenic gas present in the water well was compared with gas composition and isotope results from the bradenheads and production casings of 15 nearby oil&gas wells. A consultant assessed that the methane present in water well #750159 showed signs of natural attenuation and thus its origin could not be determined. The COGCC determined that there was no ongoing source and the methane was attenuating. Kerr McGee voluntarily provided a substitute source of potable water for the landowner. On 10/11/2013, a different landowner opened complaint #200388222 regarding a wellhouse fire that had occurred in the previous year. The water well (FacID #752810) was 69 m deep and completed in the confined Laramie-Fox Hills aquifer. A sample collected from the water well on 9/6/2013 indicated the presence of thermogenic gas (Table S3.24). Gas composition and isotope analyses from 14 nearby oil&gas wells were compared to the sample taken from the water well. During the investigation, a casing leak in the UPRR 22 Pan Am J #1 (API # 05-123-08161) oil&gas well was discovered (depth not indicated). The well was repaired and eventually plugged and abandoned on 4/9/2012. Although surface casing was set to 195 m, below the modeled base of the Laramie-Fox Hills aquifer at that location (177 m), geophysical logs from five wells in adjacent sections (https://data.colorado.gov/Water/DWR-Well-Geophysical-Log/cfyk-gwjj) indicate the base of the Laramie-Fox Hills at > 195 m depth. Thus, because of complex Laramie-Fox Hills stratigraphy in the area, the UPPR 22 Pan Am J #1 is assumed to have short surface casing. Methane present in water well #752810 and water well #750159 matched the characteristics of gas from the bradenhead of the UPRR 22 Pan Am J #1. Kerr McGee agreed to provide potable water for the landowners with impacted wells and both complaints were closed on 6/30/2014. An overview of the complaint investigation is shown in Figure S3.24.

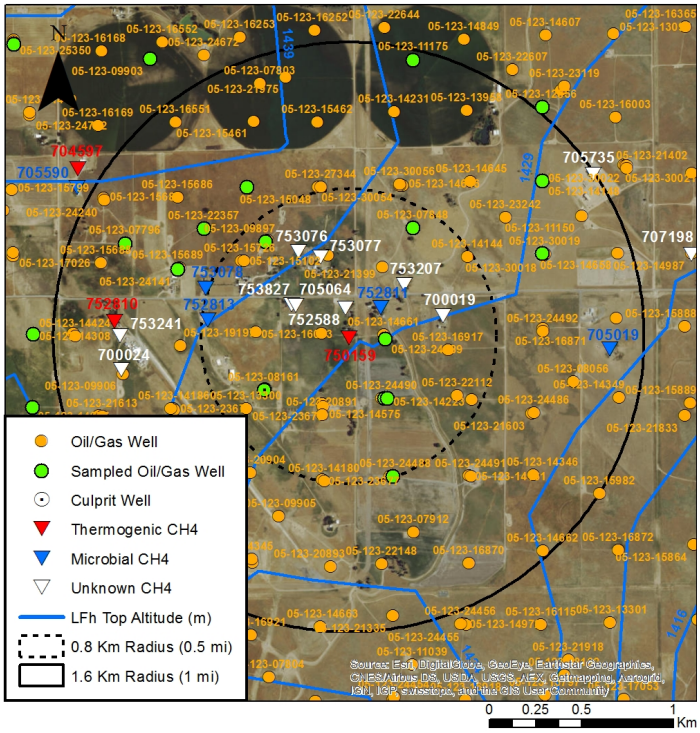

Figure S3.24 - Map view of Case #24. All of the completed oil and gas wells and environmental samples collected by the COGCC are shown from the time of the incident. The altitude contour lines of the Laramie-Fox Hills aquifer demonstrate the dip of the formation.

Table S3. 24 - Summary of samples collected for gas and isotope analyses in Case #24.

Facility I.D. or Well API Number	Completion Formation	Sample Date	Lab	CH_4 (mg/l)	C_1 (%)	C_2 (%)	C_3 (%)	iC_4 (%)	nC_4 (%)	$C_1/(C_2+C_3)$	$\delta^{13}C_{C1}$ (‰)	$\delta^{13}C_{C2}$ (‰)	$\delta^{13}C_{C3}$ (‰)	$\delta^{2}H_{C1}$ (‰)
Water Well														
750159	LFh	9/23/10	Isotech	n/a	74.94	3.88	0.59	0.23	0.04	16.76	-45.82	-28.26	-22.42	-220.5
750159	LFh	9/5/13	Isotech	7	31.92	2.01	0.16	0.02	0.02	14.71	-45.5	-27.98	-23.8	-213.7
752810	LFh	9/6/13	Isotech	6.5	16.36	2.02	0.49	0.06	0.10	6.52	-46.1	-29.15	-25.74	-217.2
Oil&Gas Well														
05-123-08161 (Annulus)	J-Sand	11/22/10	Isotech	n/a	80.68	11.44	3.67	0.56	0.93	5.34	-45.21	-28.87	-25.82	-217.8

Case #25 (Unresolved, 1 water well impacted):

Complaint # 200315938 was opened with the COGCC on 7/13/2011 when a landowner asked to have their water well (FacID # 708101) sampled. The water well was completed in the confined Laramie-Fox Hills aquifer at a depth of 264 m. Two samples were taken from the water well on 7/8/2011 and 7/25/2011. Methane was found in both of these samples with a composition and isotopic signature that indicated it was of thermogenic origin (Table S3.25). Iron related bacteria was also found in the 7/25/2011 sample. Kerr McGee/Anadarko voluntarily provided the landowner with a substitute water source. This complaint investigation is still open with the COGCC and there were no documents present in the online database that suggested a culprit oil&gas well had been identified. An overview of the complaint investigation is shown in Figure S3.25.

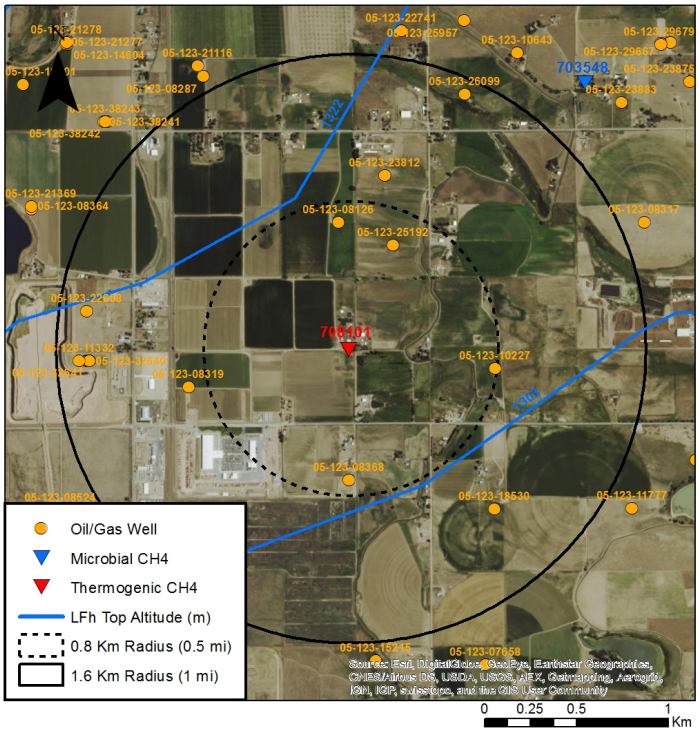

Figure S3.25 - Map view of Case #25. All of the completed oil and gas wells and environmental samples collected by the COGCC are shown from the time of the incident. The altitude contour lines of the Laramie-Fox Hills aquifer demonstrate the dip of the formation.

Table S3.25 - Summary of samples collected for gas and isotope analyses in Case #25.

Facility I.D. or Well API Number	Completion Formation	Sample Date	Lab	CH_4 (mg/l)	C_1 (%)	C_2 (%)	C_3 (%)	iC_4 (%)	nC_4 (%)	$C_1/(C_2+C_3)$	$\delta^{13}C_{C1}$ (‰)	$\delta^{13}C_{C2}$ (‰)	$\delta^{13}C_{C3}$ (‰)	$\delta^{2}H_{C1}$ (‰)
Water Well														
708101	LFh	7/8/11	Accutest/ Isotech	13.8	79.1	8.41	n/a	0.59	0.68	9.4	n/a	n/a	n/a	n/a
		7/25/11	TestAmerica/ Isotech	28	74.63	8.90	3.44	0.72	0.76	6.0	-50.87	-30.47	-26.19	-237.8

Case #26 (Wellbore failure: Short surface casing, 2 water wells impacted):

On 4/10/2012, complaint # 200371511 was opened with the COGCC when Encana Corporation reported finding 13.2 mg/l of methane in a water well (FacID #740049) during baseline sampling. The water well was completed in the confined Laramie-Fox Hills aquifer at a depth of 177 m. Baseline sampling also revealed 24.6 mg/l of methane in a second nearby water well (FacID #750060) completed in the confined Laramie-Fox Hills aquifer at a depth of 201 m. Gas composition and isotope analyses determined that the gas present in water well # 750060 was a mixture of microbial and thermogenic gas. Gas present in water well # 740049 was characteristic of thermogenic gas (Table S3.26). The Davis Gas Unit #1 (API # 05-123-08926), a nearby oil&gas well, was constructed with surface casing too shallow to protect the Laramie-Fox Hills aquifer. Surface casing in the Davis Gas Unit #1 well was set to 65 m, which was shallower than the depth of the water well and above the bottom of the Laramie-Fox Hills formation at that location (190 m). On 6/20/2012 the Davis Gas Unit #1 well underwent remedial cementing at depths of 0-120 m, 881-1247 m and 1369-2161 m. It is not clear why the remedial cementing did not extend below the base of the Laramie Fix Hills formation. Bradenhead pressure measured zero before (7/7/2010) and after (4/15/2015) the remedial the cement job. No gas composition or isotopic analyses were available for the Davis Gas Unit #1. This complaint investigation was closed on 12/5/2012 and the COGCC did not issue a NOAV to any operators. An overview of the complaint investigation is shown in Figure S3.26.

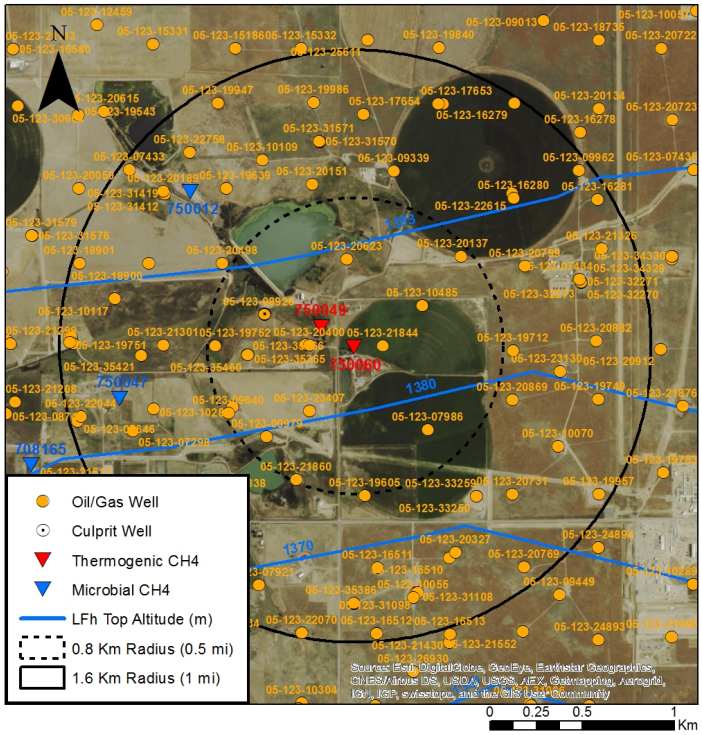

Figure S3.26 - Map view of Case #26. All of the completed oil and gas wells and environmental samples collected by the COGCC are shown from the time of the incident. The altitude contour lines of the Laramie-Fox Hills aquifer demonstrate the dip of the formation.

Table S3.26 - Summary of samples collected for gas and isotope analyses in Case #26.

Facility I.D. or Well API Number	Completion Formation	Sample Date	Lab	CH_4 (mg/l)	C_1 (%)	C_2 (%)	C_3 (%)	iC_4 (%)	nC_4 (%)	$C_1/(C_2+C_3)$	$\delta^{13}C_{C1}$ (‰)	$\delta^{13}C_{C2}$ (‰)	$\delta^{13}C_{C3}$ (‰)	$\delta^{2}H_{C1}$ (‰)
Water Well														
740060	LFh	3/28/13	Accutest/ Isotech	13.2	79.27	6.59	1.9	0.29	0.37	9.33	-56.25	n/a	n/a	-244.7
750049	LFh	4/9/12	Accutest/ Isotech	24.6	82.3	9.31	2.77	0.47	0.57	6.81	-49.94	-29.4	-25.4	-235.8

Case #27 (Wellbore failure: Short surface casing, 4 water wells impacted):

Complaint #200402859 was reported on 4/22/2014 by a landowner experiencing discoloration in their water well (FacID # 753196). The water well was completed in the confined Laramie-Fox Hills aquifer at a depth of 256 m. Initial analysis of the water well indicated a methane concentration of 18 mg/l and high concentrations of C_2+ alkanes, characteristic of thermogenic gas from the Sussex formation (Table S3.27). The COGCC identified four other water wells within a 0.75 mile radius of the water well for which the original complaint was filed and collected additional samples. Methane was found in a nearby water well (FacID #753680) at a concentration of 16 mg/l. Gas composition and isotope analyses of the samples from this water well indicated that the gas was of a mixed microbial and thermogenic origin. The COGCC contacted operators with oil&gas wells within 0.75 mile radius of the impacted water wells. The construction details and bradenhead pressures of 85 oil&gas wells were inspected by four separate operators. Four oil&gas wells close to the impacted water wells were found to be producing from the Sussex formation: the Amoco-Charter-Schneider U B #6 (API #05-123-07787), the Amoco-Charter-Schneider 12 (API #05-123-09135), the Wagner A-2 (API #05-123-08850) and the Seltzer 1-A (API# 05-123-08471). Bradenhead tests conducted on all four oil&gas wells on 6/23/2010 and 6/26/2014 indicated no significant bradenhead pressure in any of the wells. No gas composition or isotope analyses were available for these oil&gas wells. All of the wells were installed with surface casing that was not deep enough to protect the Laramie-Fox Hills aquifer: for example, the Amoco-Charter-Schneider U B #6 well had surface casing set to 62 m, which was shallower than the depth of the water well and above the bottom of the Laramie-Fox Hills formation at that location (286 m). For these reasons, K P Kauffman Company Inc., the operator of the four oil&gas wells, was issued a NOAV. This complaint investigation is still open with the COGCC. An overview of the complaint investigation is shown in Figure S3.27.

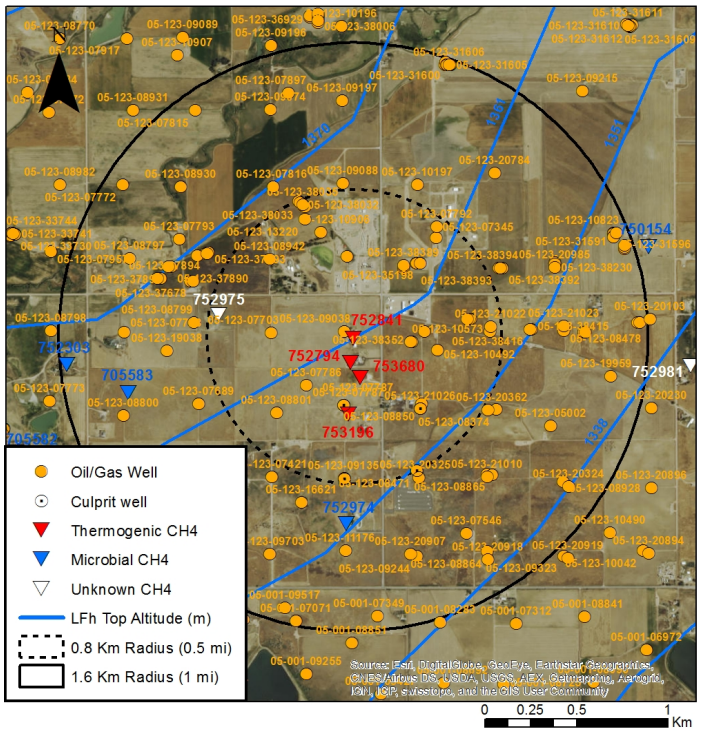

Figure S3.27 - Map view of Case #27. All of the completed oil and gas wells and environmental samples collected by the COGCC are shown from the time of the incident. The altitude contour lines of the Laramie-Fox Hills aquifer demonstrate the dip of the formation.

Table S3.27 - Summary of samples collected for gas and isotope analyses in Case #27.

Facility I.D. or Well API Number	Completion Formation	Sample Date	Lab	CH_4 (mg/l)	C_1 (%)	C_2 (%)	C_3 (%)	iC_4 (%)	nC_4 (%)	$C_1/(C_2+C_3)$	$\delta^{13}C_{C1}$ (‰)	$\delta^{13}C_{C2}$ (‰)	$\delta^{13}C_{C3}$ (‰)	$\delta^{2}H_{C1}$ (‰)
Water Well														
752841	LFh	5/11/12	ALS/Isotech	7.21	39.04	0.66	0.25	0.04	0.06	43.3	-69.27	n/a	n/a	-257.9
752794	LFh	9/4/13	ALS/DIG	1	5.13	0.2	0.09	0.02	0.02	17.6	-63.1	n/a	n/a	-276
753196	LFh	3/27/14	ALS/Isotech	18	64.41	7.73	2.36	0.266	0.464	6.38	-54.63	-32.06	-27.56	-241.9
753680	LFh	6/16/14	Isotech	16	50.44	3.5	1.01	0.096	0.18	11.18	-63.04	-32.18	-27.4	-246.7

Case #28 (Unresolved, 1 water well impacted):

Complaint # 200378738 was opened with the COGCC on 4/23/2013 when methane was observed in a landowner's water well (FacID # 752520) during baseline sampling. The water well was 96 m deep and completed in the confined Laramie-Fox Hills aquifer. Gas samples were collected from the water well on 7/16/2013 and 7/15/2014. Methane was detected in these samples in concentrations that ranged between 24-26 mg/l. Gas composition and isotope analyses of the samples indicated that the gas present in the water well was a mixture of microbial and thermogenic methane (Table S3.28). Additional sampling on 11/18/2014 discovered BTEX compounds in the impacted water well. Kerr McGee/Anadarko began an investigation of oil&gas wells within a 0.5 mile radius of the impacted water well after the complaint was opened. The HSR Bates 16-7 (API # 05-123-16518) registered an elevated bradenhead pressure of 1,469 kPag (213 psig) on 4/11/2013. The HSR Bates 16-7 well was remediated on 5/17/2014 and no casing leaks were reported during the remediation process. The investigation is still ongoing and no geochemical data has been made available on the HSR Bates 16-7 well. Complaint # 200311007 is still open with the COGCC and no additional documents were available that indicated that a culprit oil&gas well has been identified that or a NOAV has been issued. An overview of the complaint investigation is shown in Figure S3.28.

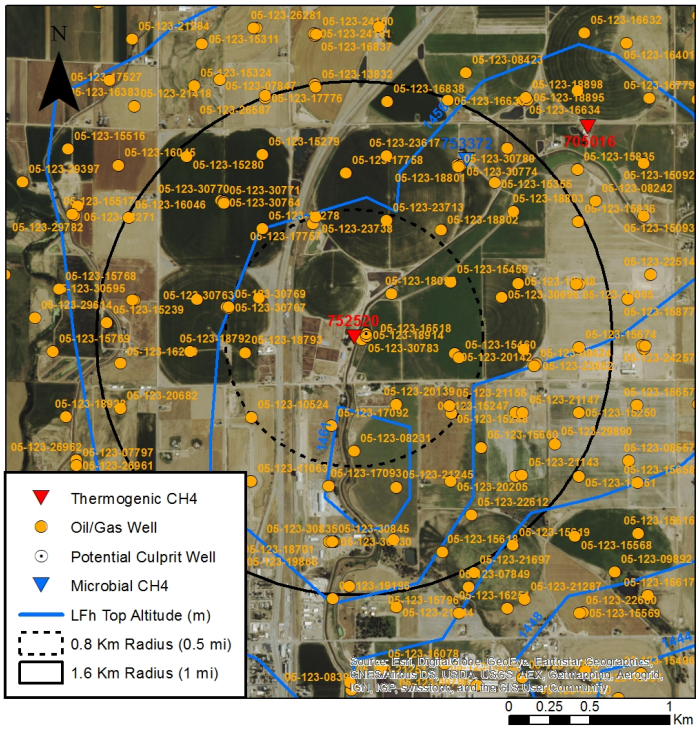

Figure S3.28 - Map view of Case #28. All of the completed oil and gas wells and environmental samples collected by the COGCC are shown from the time of the incident. The altitude contour lines of the Laramie-Fox Hills aquifer demonstrate the dip of the formation.

Table S3.28 - Summary of samples collected for gas and isotope analyses in Case #28.

Facility I.D. or Well API Number	Completion Formation	Sample Date	Lab	CH_4 (mg/l)	C_1 (%)	C_2 (%)	C_3 (%)	iC_4 (%)	nC_4 (%)	$C_1/(C_2+C_3)$	$\delta^{13}C_{C1}$ (‰)	$\delta^{13}C_{C2}$ (‰)	$\delta^{13}C_{C3}$ (‰)	$\delta^{2}H_{C1}$ (‰)
Water Well														
752520	LFh	7/16/13	ALS/Isotech	26	70.19	9.63	4.47	0.53	0.95	4.97	-48.2	n/a	n/a	-235.0
		7/15/14	ALS/Isotech	24	70.98	8.29	3.63	0.38	0.73	5.95	-52.3	-33.71	-29.19	-239.2

Case #29 (Unresolved, 1 water well impacted)

Complaint #200378738 was opened by a landowner on 7/15/2013 concerned about methane gas in their water well (FacID # 752971). The water well was completed in the confined Laramie-Fox Hills aquifer at a depth of 253 m. Gas isotope and composition analyses from a sample collected on 7/16/2013 indicated the presence of mixed microbial and thermogenic methane in the water well (Table S3.29). This investigation is still in progress with the COGCC and no other documents were available in their database regarding the complaint. An overview of the complaint investigation is shown in Figure S3.29.

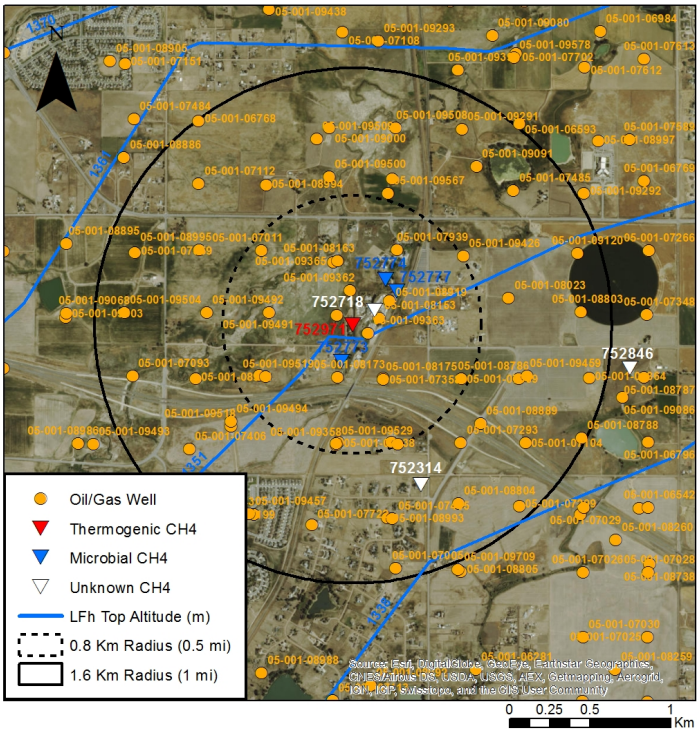

Figure S3.29 - Map view of Case #29. All of the completed oil and gas wells and environmental samples collected by the COGCC are shown from the time of the incident. The altitude contour lines of the Laramie-Fox Hills aquifer demonstrate the dip of the formation.

Table S3.29 - Summary of samples collected for gas and isotope analyses in Case #29.

Facility I.D. or Well API Number	Completion Formation	Sample Date	Lab	CH_4 (mg/l)	C_1 (%)	C_2 (%)	C_3 (%)	iC_4 (%)	nC_4 (%)	$C_1/(C_2+C_3)$	$\delta^{13}C_{C1}$ (‰)	$\delta^{13}C_{C2}$ (‰)	$\delta^{13}C_{C3}$ (‰)	$\delta^{2}H_{C1}$ (‰)
Water Well														
752971	LFh	7/16/13	Isotech	n/a	45.15	2.28	0.86	0.13	0.20	14.37	-61.40	-33.40	-29.80	-32.70

Case #30 (Unresolved, 3 water wells impacted):

Complaint #200409931 was opened with the COGCC on 8/8/2013 when a landowner reported methane in their water well (FacID #752764). The impacted water well was drilled to a depth of 134 m and completed in the confined Laramie-Fox Hills aquifer. An initial sample was collected from the water well by the COGCC on 8/8/2014. Methane was found in the water well at a concentration of 2.8 mg/l. Gas composition and isotope analyses indicated the presence of thermogenic gas in the water well (Table S3.30). Additional samples taken from the water well on 10/7/2013 and 6/11/2014 found thermogenic methane concentrations of 1.6 mg/l and 4.4 mg/l. Two other water wells were identified in the vicinity of the original well with methane present. Water well #753242 was completed in the confined Laramie-Fox Hills aquifer at a depth of 76 m. Analyses of gas samples taken from water well #753242 on 4/24/2014 indicated the presence of mixed microbial and thermogenic gas. The third water well (FacID #700018), 110 m deep and completed in the confined Laramie-Fox Hills aquifer, was sampled on 7/9/2014. The concentration of methane in the water well was 9.2 mg/l and the gas composition and isotopic signature indicated that it was of a mixed microbial and thermogenic origin (Table S3.30). COGCC identified 89 oil&gas wells within a 0.75 mile radius of the impacted water wells. The COGCC asked the operators to look into the construction of these oil&gas wells and assess whether or not the bradenheads were overpressured. Fifteen of the nearby wells had significant bradenhead pressures over 689.5 kPag (100 psig). This complaint investigation is still open with the COGCC. No culprit oil&gas wells have yet been identified and no operators have received a NOAV. An overview of the complaint investigation is shown in Figure S3.30.

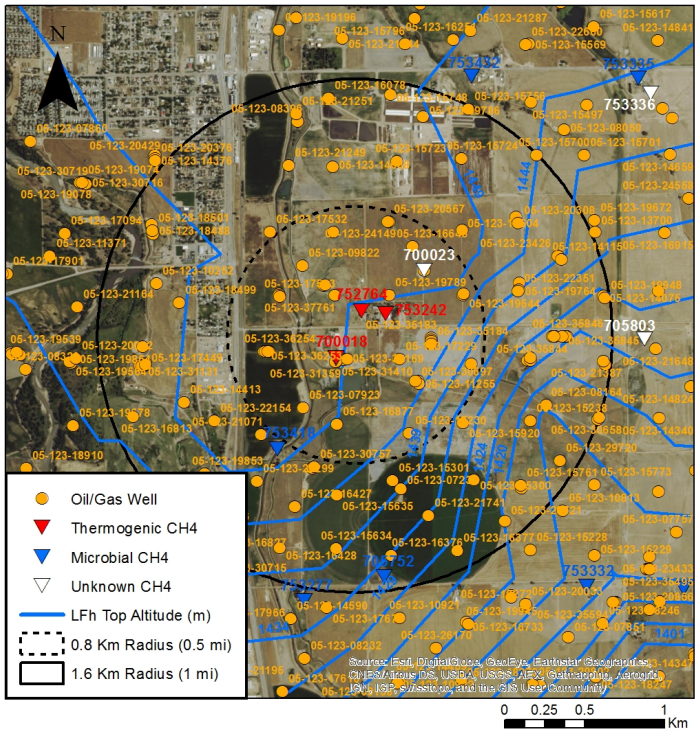

Figure S3.30 - Map view of Case #30. All of the completed oil and gas wells and environmental samples collected by the COGCC are shown from the time of the incident. The altitude contour lines of the Laramie-Fox Hills aquifer demonstrate the dip of the formation.

Table S3.30 - Summary of samples collected for gas and isotope analyses in Case #30.

Facility I.D. or Well API Number	Completion Formation	Sample Date	Lab	CH_4 (mg/l)	C_1 (%)	C_2 (%)	C_3 (%)	iC_4 (%)	nC_4 (%)	$C_1/(C_2+C_3)$	$\delta^{13}C_{C1}$ (‰)	$\delta^{13}C_{C2}$ (‰)	$\delta^{13}C_{C3}$ (‰)	$\delta^{2}H_{C1}$ (‰)
Water Well														
752764	LFh	8/15/13	ALS/DIG	2.8	10.28	0.70	0.20	0.03	0.03	11.42	-46.3	-29.5	-25.1	-213.0
753242	LFh	4/24/14	Isotech	20	57.74	2.23	0.69	0.10	0.15	19.77	-63.46	-30.04	-26.34	-246.1
700018	LFh	7/9/14	ALS/Isotech	9.2	41.15	0.19	0.04	0.02	0	n/a	-68.87	-33.6	n/a	-253.6

Case #31 (Unresolved, 1 water well impacted):

A landowner contacted the COGCC on 2/10/2014 to open Complaint # 200398569 and request sampling of their water well (FacID # 752922) due to signs of gas contamination. The 158 m deep water well was completed in the confined Laramie-Fox Hills aquifer. Gas samples were taken from the water well on 2/26/2014 and 4/25/2014. Methane concentrations between 37 and 39 mg/l were found in the well. The 4/25/2014 sample also contained 8.7 mg/l of ethane and 5 mg/l of propane. Composition and isotope analyses indicated the presence of mixed microbial and thermogenic methane in the water well in a sample collected 2/26/2014 and thermogenic methane in the sample collected 4/25/2014 (Table S3.31). The COGCC had previously sampled the landowner's water well on 7/29/1998 and 3/29/2012, and both of these samples indicated the presence of microbial methane. This complaint investigation is still ongoing. No additional documents were available in the COGCC database indicating that a Notice of Alleged Violation has been issued or that culprit oil&gas well has been found. An overview of the complaint investigation is shown in Figure S3.31.

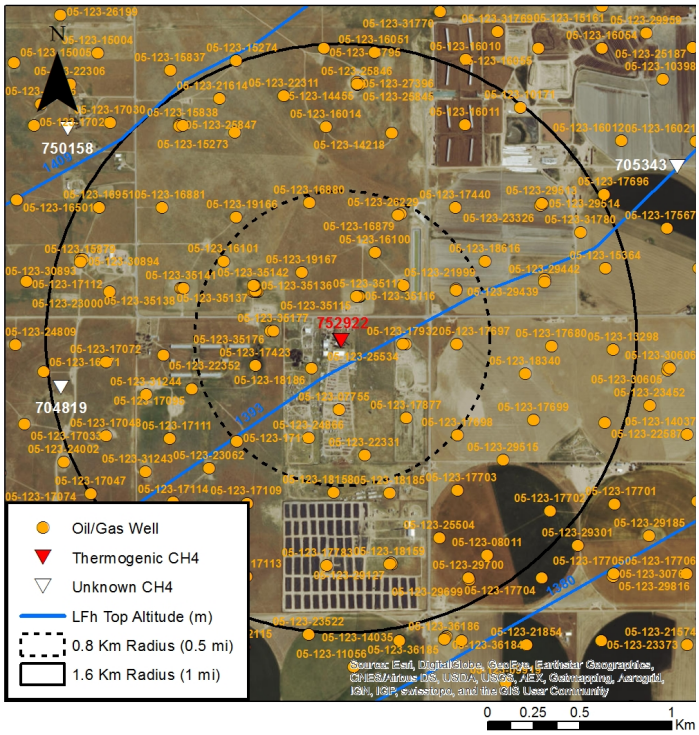

Figure S3.31 - Map view of Case #31. All of the completed oil and gas wells and environmental samples collected by the COGCC are shown from the time of the incident. The altitude contour lines of the Laramie-Fox Hills aquifer demonstrate the dip of the formation.

Table S3.31 - Summary of samples collected for gas and isotope analyses in Case #31.

Facility I.D. or Well API Number	Completion Formation	Sample Date	Lab	CH_4 (mg/l)	C_1 (%)	C_2 (%)	C_3 (%)	iC_4 (%)	nC_4 (%)	$C_1/(C_2+C_3)$	$\delta^{13}C_{C1}$ (‰)	$\delta^{13}C_{C2}$ (‰)	$\delta^{13}C_{C3}$ (‰)	$\delta^{2}H_{C1}$ (‰)
Water Well														
752922	LFh	2/26/14	TestAmerica /Isotech	39	77.93	6.17	2.61	0.40	046	8.87	-56.09	-30.01	-26.54	-247.4
		4/25/14	ALS/Isotech	37	79.4	7.96	3.23	0.44	0.58	7.09	-54.19	-30.1	-26.76	-241.7

Case #32 (Unresolved, 1 water well impacted):

The COGCC sampled a 101 m deep domestic water well (FacID #753244) completed in the Laramie-Fox Hills aquifer on 4/24/2014. Concentrations of methane, ethane, and propane in the water well sample were 4.9 mg/l, 1.5 mg/l, and 0.8 mg/l respectively. Gas and isotope analyses indicated that the gas was thermogenic in origin (Table S3.32). The COGCC has not yet opened a complaint investigation based on this sample and no additional documents were available in the online database. Figure S3.32 portrays the impacted water well and the surrounding region.

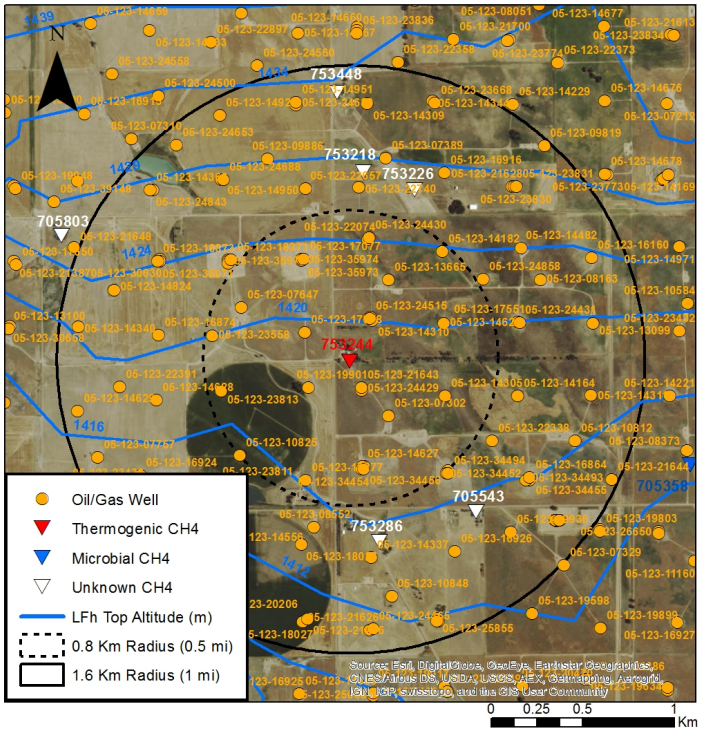

Figure S3.32 - Map view of Case #32. All of the completed oil and gas wells and environmental samples collected by the COGCC are shown from the time of the incident. The altitude contour lines of the Laramie-Fox Hills aquifer demonstrate the dip of the formation.

Table S3.32 - Summary of samples collected for gas and isotope analyses in Case #32.

Facility I.D. or Well API Number	Completion Formation	Sample Date	Lab	CH_4 (mg/l)	C_1 (%)	C_2 (%)	C_3 (%)	iC_4 (%)	nC_4 (%)	$C_1/(C_2+C_3)$	$\delta^{13}C_{C1}$ (‰)	$\delta^{13}C_{C2}$ (‰)	$\delta^{13}C_{C3}$ (‰)	$\delta^{2}H_{C1}$ (‰)
Water Well														
753244	LFh	4/24/14	Isotech	4.9	20.8	2.86	1.04	0.16	0.24	5.33	-45.86	-29.56	-26.4	-225.2